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AN INVESTIGATION OF AIRBORNE DISPLAYS AND CONTROLS FOR SEARCH AND RESCUE (SAR). VOLUME VI. AVIONICS REQUIREMENTS FOR THE HH-53C HELICOPTER

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Honeywell, Incorporated

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Requirements for the HH-53C Helicopter

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SEARCH AND RESCUE (SAR)

by O. H. Lindquist, B.A. Olson, A. Jones, J. W. Wingert
Honeywell Inc.

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13 ABSTRACT
An analytical study was conducted to define the avionics system and the display and controls concept required for the HH-53C helicopter so that it could accomplish the USAF's all-weather SAR mission. The study tasks included development of an avionics concept based on a representative mission scenario, avionics and sensor package selection, a man/machine function allocation and crew workload analysis. A recommended avionics configuration was defined. The HH-53C can be upgraded by an avionics configuration, within the cost constraints, to perform the all-weather SAR mission. This upgraded HH-53C can be operated by the crew within their workload limitations.

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FOREWORD

The final report is submitted in fulfillment of Office of Naval Research Contract No. N00014-69-C-0460, Contract Authority NR213-072. Commander J. E. Hammack of ONR (Code 461) served as chairman of the Joint Service SAR Working Group that monitored the study. The other group members were:

- U.S. Army: Mr. A. Linder, Mr. S. Domeshek
- U.S. Navy: Mr. J. Wolin, Commander R.J. Hartranft
- U.S. Coast Guard: Commander B.L. Solomon, Lieutenant Commander L.A. Kidd
- U.S. Air Force: Colonel W.D. Knox, Mr. R.A. Bondurant

The work described in this report was performed by Honeywell's Systems and Research Center during the period December 1971 through May 1972. Mr. O.H. Lindquist served as Program Manager. Technical guidance was provided by Mr. R.A. Bondurant, III, AFFDL/FGR.

In addition to the authors listed, Messrs. P.S. Kilpatrick, G. Asselstine, F.A. Moynihan, and R.G. Santella of Honeywell made valuable contributions.

This report is published as Volume VI of a series of reports titled "An Investigation of Airborne Displays and Controls for Search and Rescue (SAR)". This study is an extension of the program reported in Volumes I, II, III, IV, (published July 1971) and V. It is the first of four applications of the technique and information made available by the Joint Service Study Program. The earlier reports were:

- Volume I — JANAIR Report No. 701219: Summary
- Volume II — JANAIR Report No. 701220: SAR Requirements and Technological Survey
- Volume III — JANAIR Report No. 701221: Avionics Analysis and System Synthesis
- Volume IV — Results of Honeywell/Bell Mockup Review
- Volume V — Avionics Requirements for a Utility Aircraft

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SECTION I

INTRODUCTION AND SUMMARY

This document, Volume VI of an eight-volume series, summarizes the Search and Rescue (SAR) study of the avionics system and the display and controls concept definition for the U.S. Air Force HH-53C helicopter. The study tasks included development of an avionics concept based on a representative mission scenario, avionics and sensor package selection, a man/machine function allocation and crew workload analysis. A recommended avionics configuration is defined.

The study requirements and constraints were defined by Mission "B" of the Joint Services SAR study, the PAVE LOW baseline vehicle configuration and the HH-53C SAR mission operation requirements. The primary results of the study are: (1) the HH-53C can be upgraded by avionics configuration to perform the all-weather SAR mission within the cost constraints; and (2) the upgraded HH-53C can be operated by the crew within their workload limitations provided communication procedures are developed to reduce the crew communication workload.

Honeywell conducted a Joint Services SAR study which assumed a jointly developed hypothetical vehicle which could be used for common SAR equipment procurement. These results are documented in the first four volumes of the series. The Joint Services SAR study developed a wealth of information which could be interpolated into the probable environment of the individual service for the 1972-1974 period. Since the program could not identify a Joint Services helicopter due to program changes, applications of the study were defined for each participating service. Volume V describes an avionics system concept for a U.S. Coast Guard multimission fixed-wing twin-engine aircraft. Volume VII describes an avionics system concept for a U.S. Navy SAR helicopter. Volume VIII describes an avionics system concept for a U.S. Army SAR application for the UTTAS vehicle.

The Joint Services SAR study objectives were to:

- Provide a means of coordination of four services' SAR requirements
- Develop a systems analysis technology which includes the crew
- Identify the common SAR requirements for 1972-1974 period
- Define a best SAR system to meet these requirements

- Evaluate a system configuration
- Identify problem areas and needed R&D effort
- Express study results in a mockup review.

One output of the Joint Services SAR study consisted of a recommended display and control configuration for a hypothetical Search and Rescue helicopter, an evaluation of its application to SAR missions, and a recommendation as to needed R&D in avionics. This configuration development used systematic derivation of mission, function and equipment requirements, the selection of candidate systems from a technology survey, and the application of man/machine analysis to evaluate the candidate systems. The configuration was modeled in a cockpit mockup and is described in detail in Volume IV.

Two multiservice teams reviewed the recommended configuration and evaluated it in terms of the SAR mission segments information requirements and estimated man/machine performance of the system. The evaluation teams' findings are summarized in a recommended instrument panel arrangement.

The staff of the Aviation Branch, U.S. Army Human Engineering Laboratories, used the panel arrangements of the Joint Services Study together with consideration of the Army's SAR requirements to develop the final panel arrangement.

This document reports the results of a study to fit the final panel arrangement and the associated avionics into the HH-53C to enable this vehicle to accomplish the USAF SAR missions for the near-term period. The final output of the study reported here is a recommended display and control configuration for the HH-53C helicopter. Alternative configurations are discussed. The configuration was developed by the use of the methodology and the data resources generated in the Joint Services SAR study. Specific function and equipment requirements were coordinated with USAF SAR representatives. The selection of candidate avionic systems was made from an updated technology survey. Man/machine analysis techniques were used to evaluate the candidate systems.

SECTION II
STUDY APPROACH

This study was directed towards defining a cockpit display/control configuration/avionics complement with which a USAF crew could adequately perform its all-weather SAR mission.

The basic mission requirements were derived from the previous study, the documented operational problems of the HH-53C helicopter, the documented IFR operational problems of Air Force helicopters and coordination meetings with representatives of USAF SAR operational groups. The crew information requirements were derived from the previous study as modified by the inputs of the USAF SAR operational groups. The study tasks included:

- Review of operational problems of the HH-53C
- Identification of the status of current HH-53C avionic installations
- Adaptation of the Joint Services Study recommended avionics installation
- Formulation of alternate avionics configurations
- Evaluation of these alternative configurations
- A report on the study results

The study output included:

- A USAF SAR report with avionics recommendations
- A soft mockup of a recommended avionics display/control system for the HH-53C
- Identification of potential problems

Systems constraints such as cockpit-panel space, installation requirements, total avionics cost and weight, etc., were reviewed against the selected complement, and a number of changes were made to the avionics set to meet the constraints. The recommended avionics system concept was generated from the tradeoff studies. Tentative avionics configuration and an instrument panel arrangement were described. Areas requiring additional study were identified, such as those in which mission requirements conflict with system constraints.

The generalized study process followed in this program for selection of the recommended avionics complement is shown in Figure 1. The data base accumulated in the prior Joint Services SAR study was used extensively as background in the mission requirements definition and avionics selection.

The preliminary problem assessment was performed based on data provided by AFFDL and the ASD Helicopter Project Office. The specific areas proposed for investigation after reviewing the operation problems of the HH-53C were Communication Workload, IFR Workload Control/Display Tradeoff, Navigation (enroute and terminal) System Tradeoff, and Instrument Panel Layout. These areas were studied to define potential control/display and avionics modifications that would significantly improve the SAR mission capability of the HH-53C.

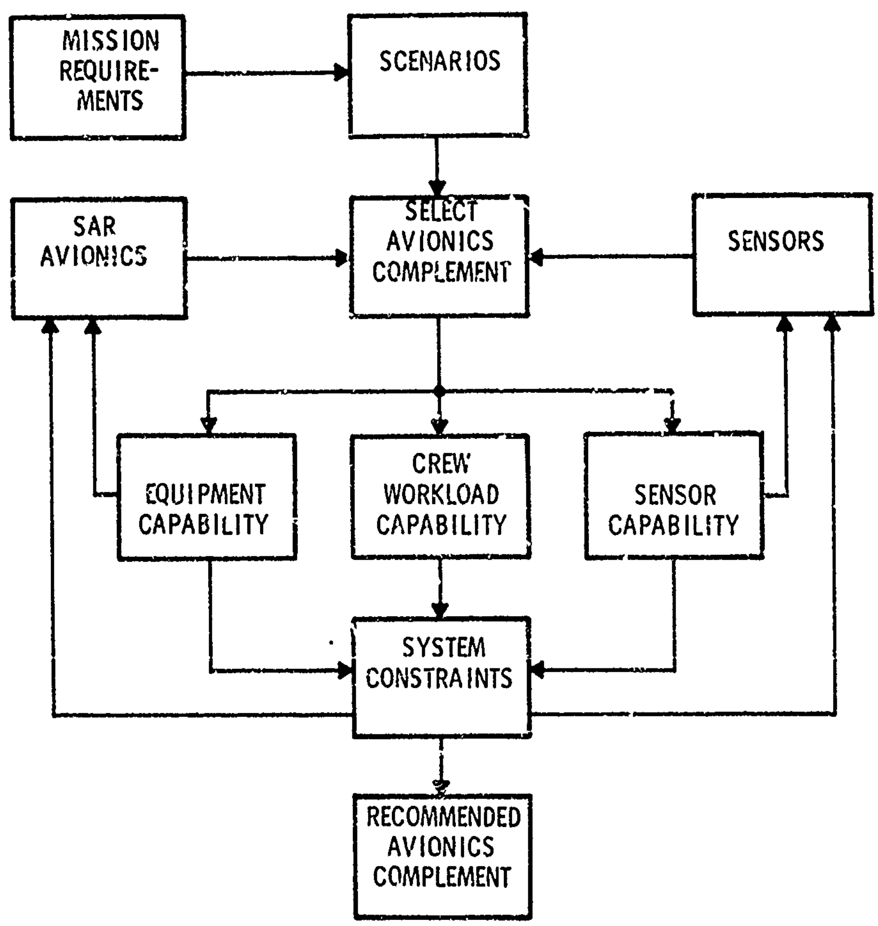


Figure 1. Program Study Process

SECTION III

STUDY REQUIREMENTS AND CONSTRAINTS

GENERAL REQUIREMENTS

The specific efforts of this study were directed to the identification of a recommended avionics cockpit configuration for a product improvement program for the HH-53C helicopter. This configuration was to be developed from off-the-shelf hardware. The configuration was to be evaluated by study of the crew/display/control interface. This interface must be designed to make fullest use of the crew's capabilities without excessive cockpit workloads.

Current developments in computer-driven CRT displays make it possible to provide the pilot and his crew with compact integrated multipurpose displays of flight-path and/or mission-management data. This display medium has sufficient versatility to permit almost any sort of information display format to be granted and to allow for the data from several sensors to be displayed in an integrated format. The majority of the "off-the-shelf" avionics sensors have their own dedicated displays while the new integrated displays are just becoming available.

Commonality with existing USAF equipment in inventory was used as one of the requirements for the recommended avionics consideration. It was not intended to overemphasize the commonality factor in the recommended avionics selection, but to establish the requirement to consider commonality.

The operational constraints were established from the body of data gathered from a survey of the SAR service organizations on the conditions under which rescue missions are now conducted. The Mission B profile from the Joint Services SAR study was modified into an all-weather rescue mission.

The general requirements that helped set the boundaries for the study include:

- The baseline vehicle is the HH-53C helicopter in the PAVE LOW and LNRS configuration.
- The selected equipment should complement the existing PAVE LOW and LNRS systems.
- Major modifications of the AFCS should not be considered.
- Flight director systems and/or pilot-assist modes are viable candidates for system retrofit.

- The improved aircraft should have all-weather mission capability.

- The radar installed in PAVE LOW is assumed adequate for terrain following for the SAR mission.

- The ELF system should be considered as the basic terminal-area navigation aid for the SAR mission.

- The system should have the capability for a one-pass approach and pickup of the rescuee.

- The system should have a precision IFR hover capability.

- The system should enable the pilot to recover the initial hover location when he drifts off.

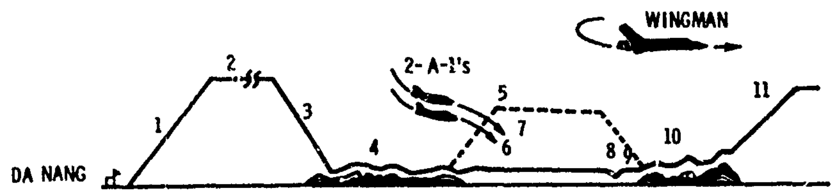
- The avionics configuration cost should not exceed $500,000 installed.

From the viewpoint of Air Force needs, the study should produce a recommended set of avionics and alternatives to enhance the SAR operational capability of the HH-53C PAVE LOW with the LNRS configuration. The recommendation should include identification of operational improvements, costs and priority for each of the suggested modifications. Information should be provided, if possible, to assist the Air Force in planning necessary development efforts leading to a flight test demonstration program. A two-aircraft prototype program may be initiated in FY74. For this purpose, consideration could be given to advanced concepts, such as helmet-mounted displays, that are not necessarily available off-the-shelf today.

MISSION PROFILE

The logical basis for the development of Mission B is discussed in Volume II. From the analysis of six representative SAR missions, a composite mission was developed that was representative of the USAF SAR mission requirements. Mission B was further modified for this study to satisfy the above general requirements (see Figure 2). This modified mission profile incorporates high-probability, difficult conditions as well as routine and worst-case conditions. This mix provides a reasonable balance of conditions for the IFR mission scenario. It is a dense-jungle pickup in hostile territory and a mountain pickup at very low light level with minimum communication with the rescuee.

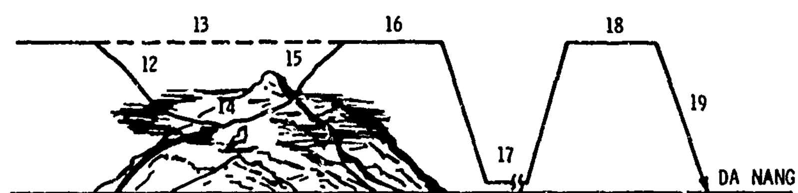
Two pilots of an F-4C aircraft eject. The SAR mission is to first rescue a communicative, healthy copilot who has descended into an enemy-infested jungle and then to locate the wounded pilot who stayed with his aircraft until



RESCUEE
- COMMUNICATIVE
- COOPERATIVE
- GOOD HEALTH

CONDITIONS
- THICK JUNGLE CANOPY
- DUSK
- CLEAR WEATHER
- o ENEMY PRESENT

1. VFR TAKE-OFF AND CLIMB-OUT
2. CRUISE TO ENEMY INFESTED TERRITORY
3. DESCENT TO TERRAIN FOLLOWING
4. TERRAIN FOLLOWING DASH TO SEARCH AREA
5. SAR NO. 2 ORBITS WITH A-1 SANDY'S
6. SAR NO. 1 SEARCH
7. SAR NO. 1 LOCATES TARGET FOR SANDY'S WITH SMOKE BOMB
8. SAR NO. 1 DESCENDS TO HOVER, LOWERS PENETRATOR, RECOVERS CO-PILOT
9. SAR NO. 1 SUPPRESSES SMALL ARMS FIRE
10. TERRAIN FOLLOWING DASH OUT OF ENEMY INFESTED TERRITORY
11. CLIMB TO 8000 FT. AND CRUISE TOWARD 2ND RESCUE



RESCUEE
- o INJURED
- o COMMUNICATIVE
- o UNCOOPERATIVE

CONDITIONS
- o 95°F
- o NEARLY DARK
- o 300 FT. CEILING
- o 0.1 MILE VISIBILITY
- o FRIENDLY TERRITORY

12. SAR NO. 2 DESCEND TO SEARCH AND MAKES RADIO CONTACT
13. SAR NO. 1 LOITERS AND ATTENDS CO-PILOT
14. SAR NO. 2 FINDS INJURED PILOT VISUALLY, HOVERS 1 FT. OFF MOUNTAIN AS CREW LOAD INJURED PILOT
15. SAR NO. 2 CLIMBS OUT AND ACCELERATES TO CRUISE
16. CRUISE TO ARTILLERY NET
17. DESCEND TO 200 FT. ABOVE ARTILLERY NET AND CLIMB BACK TO CRUISE
18. CRUISE TO DU NANG
19. DESCENT AND VFR LANDING

Figure 2. SAR Mission B Profile

it reached known friendly territory. It is a late fall evening. The downed aircraft is Maverick 1. The second F-4C loitering in the vicinity of the downed aircraft is Maverick 2. Two SAR helicopters, staged out of an auxiliary field west of Da Nang with call signs SAR 1 and 2. Two A-1's, operated by the RVN Air Force, are Dragon 1 and 2. The off-scene commander is at the RCC.

Situation

A continuation of the Vietnam conflict in SEA involves reduced but effective U.S. support of the South Vietnamese. A SAR base with a squadron of helicopters is located just west of Da Nang. It is in charge of rescue operations in an area of 150 miles radius. An F-4C is shot down near the South Vietnam/Laos border. His wingman gets and transmits the Mayday information and stands by to point out the location of the pilot. The RCC at the Da Nang SAR base declares an emergency and sends two SAR helicopters and two A-1 (Sandy) escorts to perform the rescue operation.

SAR Mission

Following an interdiction strike at the Ho Chi Minh trail, Maverick 1 took a hit from 37-mm antiaircraft fire during his pullup. Aircraft response to control inputs was sluggish laterally. Flight was continued for a few seconds while a damage survey was attempted. Maverick 1 squawked "Mayday" and reported he was hit and had impaired control response. Just after this transmission, Maverick 2 observed a structural panel separate from the lead aircraft which immediately began rolling. The copilot of Maverick 1 immediately ejected at an altitude of approximately 2000 feet over the local terrain, which was rough with a dense jungle cover. The local terrain elevation was approximately 3000 feet. The parachute blossomed, and Maverick 2 began an orbiting turn while broadcasting a "Mayday" squawk. The parachute was observed entering the jungle canopy. The time of the first ejection was 1900 hours.

Maverick 2 requested that the Maverick 1 pilot eject. Maverick 1 replied that he was slightly wounded and would eject after passing east into friendly territory. Maverick 2 observed the crippled plane heading toward mountainous terrain; the pilot ejected without further communication.

Maverick 2 broadcast a position report to the RCC and advised that he could loiter 0:30 minutes with his available fuel. At 1905 hours, the copilot of Maverick 1 contacted Maverick 2 on the SAR survival radio frequency of 243.0 MHz. He reported being on the jungle floor with only minor scratches and bruises.

The area where the copilot of Maverick 1 had ejected was known to be infested with enemy troops. RCC expected that rescue would have to be effected as soon as possible because enemy troop units would be hunting for survivors. The two RVN A-1's (Dragon 1 and 2) that had just departed Quang Tri with a full ordnance load were diverted to the rescue area to relieve Maverick 2. Two SAR helicopters (SAR 1 and 2) were scrambled from their base west of Da Nang at 1925 hours. Because of the urgency of the mission, they were briefed by RCC to proceed on a direct heading to the jungle rescue area. The resulting course would take them over areas of known enemy troop concentrations and antiaircraft defenses. Departure time was 1935 hours under good weather conditions. The visibility was 10 miles but was expected to deteriorate enroute since Maverick 2 was reporting 1-mile visibility. Both helicopters climbed out to 5000 feet enroute to the known unfriendly area. At 1955 hours, Maverick 2 called to report that the copilot was seeking a suitable position for the rescue attempt. He had no word on the pilot of Maverick 1. Maverick 2 advised that he would try to hold his orbiting position a few more minutes to allow arrival of the RVN A-1's (Dragon 1 and 2). They arrived at 2003 hours and Maverick 2 departed with minimum fuel.

At 2008 hours, SAR 1 and 2 descended to 20 feet over the jungle canopy and began a high-speed dash to the rescue area using a terrain-following flight path. At 2045 hours, they sighted the RVN A-1's miles off to the right of the estimated rescue location. Because of Maverick2's necessarily hasty departure, Dragon 1 and 2 had only a general idea of the location of the rescue. SAR 1 and 2 were receiving the rescue signal on ELF. SAR 1 continued on towards the rescuee, and SAR 2 continued on and called in Dragon 1 and 2 to orbit nearer the rescue site. SAR 1 climbed to 1000 feet above the terrain to get range-to-rescuee information from the ELF system. SAR 1 now came under light small arms fire and took some hits. The rescuee reported he could hear the firing, but faintly. SAR 1 now had range information and began an automatic approach to hover. SAR 2 directed Dragon 1 and 2 for suppressive fire. Dragon 1 and 2 immediately began strafing and bombing in the area designated by SAR 2. At 2120 hours, SAR 1 had a firm location on the rescuee and began to taxi over to his position in a hover mode. They began receiving small arms fire immediately which the crew returned with suppressive fire from mini-guns. The rescuee reported the firing sounded close. The jungle penetrator was lowered, and the copilot from the Maverick 1 was hoisted aboard. Small arms fire from the jungle continued but was not intense. The copilot was hoisted aboard SAR 1 at 2127 hours, and an immediate departure was made on a heading east toward an area 10 miles south of Pleiku.

A terrain-following mode was used to reduce vulnerability during the dash through the enemy troop concentration. The A-1's were dismissed. Dusk had faded into darkness as the second rescue began.

Conditions changed to a milder but foggier situation in the second search area with an estimated 0.1-mile visibility, 300-foot ceiling and gusts to 5 knots.

The pilot's approximate location in the mountain area was given by the RCC. The condition of the pilot was not known. SAR 1 and 2 climbed to a cruise altitude of 6000 feet pressure altitude. SAR 2 began to manually fly an approach and hover on the ELF guidance signals to come into a hover at 4500 feet. SAR 2 remained at 6000 feet and sighted the parachute in the trees. After 5 minutes of search from the hover, SAR 2 located the rescuee, descended to hover 1 foot off the mountain side, and the medic and the crewchief jumped out to attend to the pilot. The pilot could be moved aboard with the assist from the medic and the crewchief.

SAR 1 radioed back to RCC that the pilots had been recovered. SAR 2 climbed and accelerated to cruise speed of 150 knots at an altitude of 6000 feet. SAR 1 and 2 turned north and cruised to the first artillery net 5 miles north of Pleiku. The ground commander of the artillery net advised them to fly at 200 feet. They passed the first net and climbed back to 6000 feet. At the second artillery net 10 miles further north they are advised by the ground commander that they can fly through at their present altitude. Approximately 40 minutes later, SAR 1 and 2 arrived at the Air Force Base in Da Nang.

Table I summarizes mission phases versus functional requirements.

BASELINE VEHICLE

The HH-53C equipped with a limited night recovery system (LNRS) is the baseline vehicle. The LNRS provides a low-light-level TV system that permits night search and rescue of combat aircrew members in limited weather environments. Figure 3 describes the LNRS configuration.

The flight-control system for this helicopter is conventional except these HH-53Cs are equipped with approach and hover couplers. These couplers provide an additional AFCS function that enables the helicopter to make an automatic approach to a preselected hover altitude and then maintain stabilized hover flight during rescue and other hover operations. The couplers enable the helicopter to automatically transit from forward flight, through an approach, to a preselected hover altitude. The coupler control panel, located on the center cockpit console, contains the controls for operation of the approach and hover couplers. The LNRS helicopters have a portable limited-authority hover control stick. This control can be mounted on either the pilot's or copilot's seat. The recommended coupler approach is shown in Figure 4.

The general limitation on the HH-53C operation with the couplers engaged are:

- Maximum pitch variation is -5 degrees and +10 degrees with transients to +12.5 degrees. Maximum roll variation is 5 degrees right and 7 degrees left with transients to ±10 degrees.

Table I. Composite Mission B Conditions Summary and Segment Requirements

Mission Segment	State Conditions							Environmental Conditions					
	Time Interval (min)	Height Above Ground (ft)	Press. Altitude (ft)	Ambient Temp. (°F)	Average Speed (knots)	Distance (miles)	Maneuvers (type)	Wind (knots)	Ceiling (ft)	Visibility (miles)	Light Level (type)	Terrain (type)	Threat (type)
1. Preflight in-cockpit checkout	5	0	2000	95	0	-	-	5	Unlimited	10	Dusk	Level	None
2. Engine start, taxi, and takeoff	7	0	2000	95	50	-	Three 90-deg turns	5		10		Level	None
3. Climb enroute	1	3000	5000	84	100	1.5	Normal climb and 90-deg turn	10		10		Foothills	Small arms (SA)
4. Cruise	27 5	2200	5000	84	150	60	Four 30-deg turns	10		10		Mountains and valleys	SA and AAA
5. Rapid descent	0.5	120	3000	91	195	1.6	Dive and accel	5		4		Hills and valleys	
6. Dash at low level	31	120 to 20 (above trees)	3000 ±500		120 ±15	95	Pullups, pushovers, and seven 30-deg turns			2			
7. Rendezvous	1	120	1000		100	2	One 180-deg turn			2			
8. Search	33	120	3000		95	-	Ten 90-deg turns			1			
9. Rescue approach	2	100	3000		45	1	Slow descent			1			
10. Hover and pickup	5	100	3000		e	-	-			1			
11. Dash	2	120	3000		120	4	Accelerate and 45-deg turn			1			
12. Climb enroute	2	3400	8000	85	120	4	Rapid climb		2000	1		Mountains and valleys	
13. Cruise	1	1500	8000	85	120	2	-		3000	0.1	Dark	Mountains	None
14. Descent	1	200	6300	95	100	1	Normal dive and 90-deg turn			0.1			
15. Search	15	100	6200	95	90	-	Five 90-deg turns			0.1			
16. Low hover and pickup	10	1	6100	95	0	-	-			0.1			
17. Climb-out	1	2500	8000	85	90	1	Normal climb and 90-deg turn			0.1			
18 Cruise	4	5000	8000	85	150	15	-	10	2000	1		Mountains and valleys	SA and AAA
19. Orbit for artillery net clearance	2.5	500	8000	85	120	-	360-deg turn	10	3000				
20. Dive under artillery net and climb	6	200 to 5000	3000 to 8000	91	120	4	Steep dive-level steep climb	10	5000	2			
21. Cruise and orbit	2.5	5000	8000	85	120	6	360-deg turn	10	Unlimited	4			
22. Cruise	40	5000	8000	85	150	120	Eight 30-deg turns	10		10			
23. Descend	3	1000	3000	91	120	5	Normal descent and 90-deg turn	5		10		Foothills	SA
24. Approach	2	500	2500	91	100	2	Normal approach	5		10		Foothills	None
25. Land, taxi, shutdown	7	0	2000	91	0	-	Three 90-deg turns	5		10		Level	None

Table I. Composite Mission B Conditions Summary and Segment Requirements (Concluded)

Mission Segment	Communications To					Flight-Path Management					Environmental Monitoring				Mission Management			
	RCC	Crew	Other A/C	Other Ground	Rescuee	Flight Control	Enroute Nav.	Terminal Nav.	Terrain Following	Formation Flight	Proximity Warning	Attitude Orientation	Ground Surveill.	Air Surveill.	Systems Monitoring	Fire Control	Search Scanning	Rescue Operation
1. Preflight in-cockpit checkout	X	X		X											X			
2. Engine start, taxi, and takeoff		X		X		X							X		X			
3. Climb enroute	X	X		X		X	X				X	X	X	X	X			
4. Cruise	X		X			X	X						X	X	X			
5. Rapid descent		X	X			X						X			X			
6. Dash at low level	X	X	X			X	X		X						X			
7. Rendezvous		X	X			X		X	X			X						
8. Search		X	X		X	X		X				X	X	X			X	
9. Rescue approach		X			X	X		X				X	X			X	X	
10. Hover and pickup		X			X	X						X	X			X		X
11. Dash	X		X			X	X					X			X			
12. Climb enroute		X	X			X	X					X			X			
13. Cruise		X	X			X	X											
14. Descent		X	X			X		X	X			X						
15. Search		X	X		X	X		X	X			X	X		X		X	
16. Low hover and pickup		X			X	X		X	X			X	X		X			X
17. Climb-out	X	X	X			X	X					X		X				
18. Cruise		X	X			X	X					X		X	X			
19. Orbit for artillery net clearance			X	X		X	X					X			X			
20. Dive under artillery net and climb		X	X			X	X		X			X						
21. Cruise and orbit		X	X	X		X	X					X			X			
22. Cruise	X	X	X			X	X					X			X			
23. Descend		X		X		X		X			X	X						
24. Approach		X		X		X		X				X	X		X			
25. Land, taxi, shut-down																		

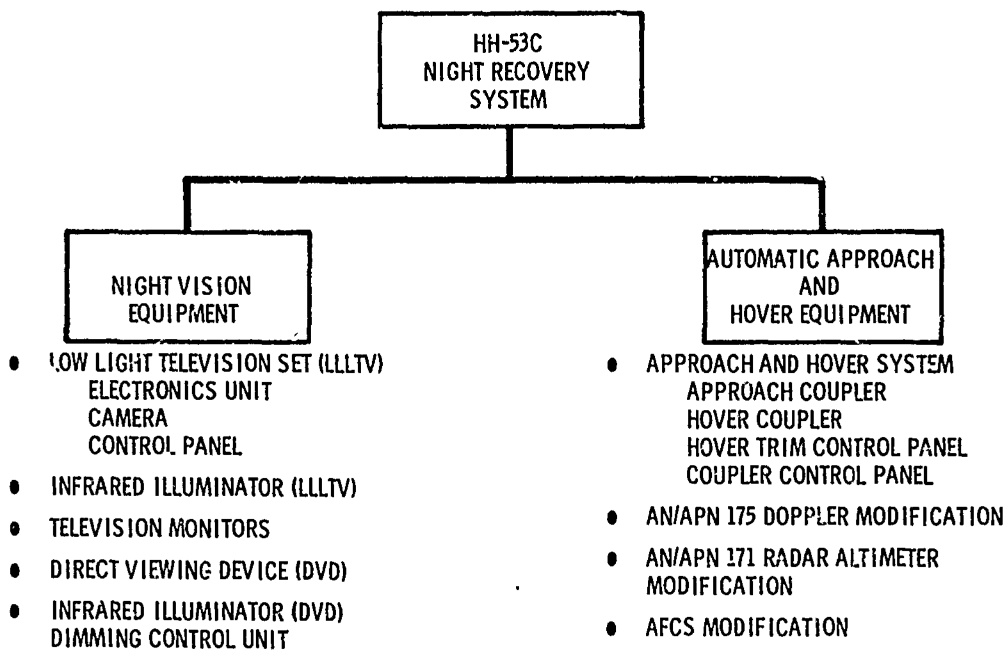


Figure 3. Baseline Vehicle Limited Night Recovery System (LRNS)

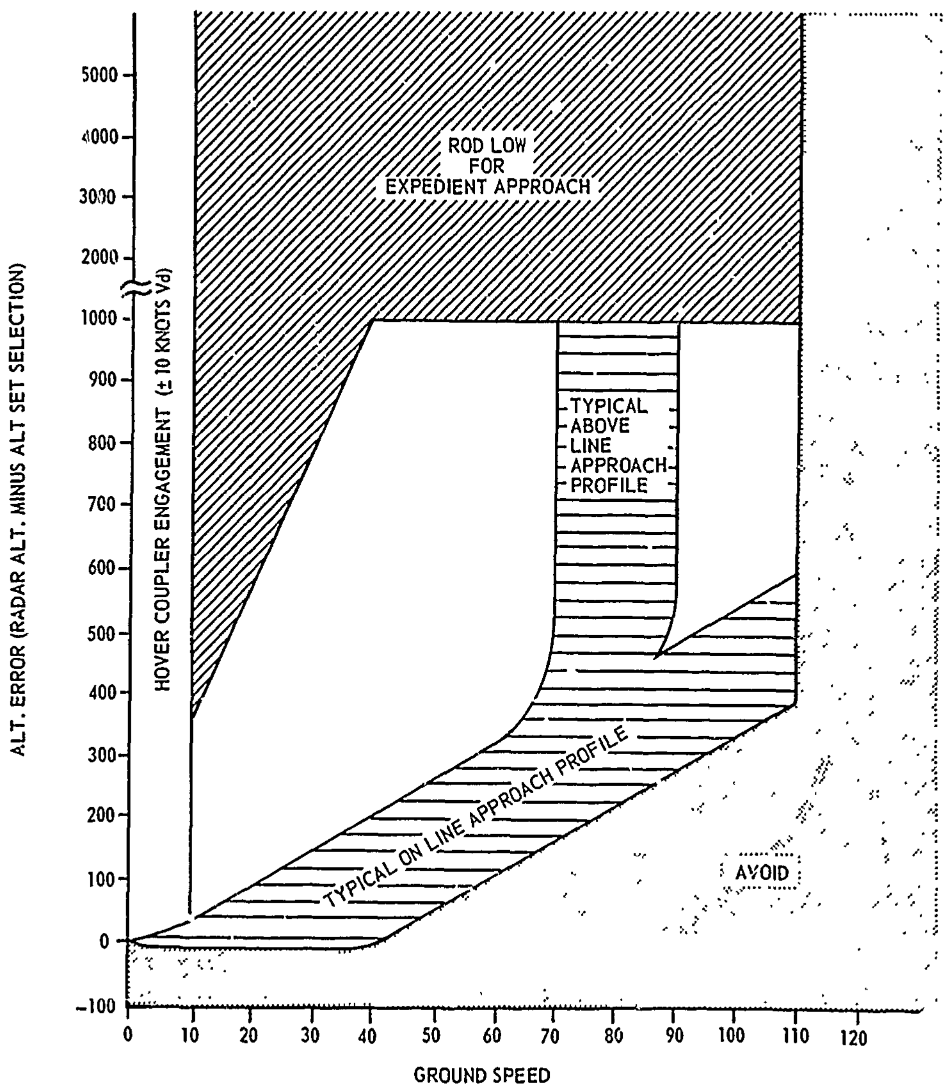


Figure 4. Automatic Approach and Hover Coupler Engagement Envelope

- Downwind approaches are to be avoided. The maximum direct crosswind for an approach or hover is 15 knots.

- Maximum doppler vertical speed during an approach is 500 ft/min with transients to 700 ft/min as indicated on the helicopter's pitot static vertical speed indicator.

- Maximum doppler vertical velocity below 40 knots is 300 ft/min.

- Maximum doppler vertical velocity during hover modes is 300 ft/min.

- The minimum hover altitude is 30 feet. Over a smooth hard surface such as asphalt the minimum altitude should be increased to 50 feet.

- The maximum vertical velocity for engagement of the coupler is +250 and -500 ft/min, respectively, as indicated by the doppler vertical speed pointer.

- Approaches should not be commenced in the avoid area of the envelope shown in Figure 4.

- Maximum groundspeed change from approach coupler engagement to deceleration is ±10 knots. The groundspeed shall not increase during the deceleration phase of the approach.

- The maximum groundspeed while operating up steep slopes is 5 knots or that which results in a rate of climb of 400 ft/min.

- Altitude changes in the increased direction should be limited so that a rate of climb of 400 ft/min is not exceeded.

- Maximum engagement speed for approach coupler is 110 KIAS.

The HH-53C helicopters, manufactured by Sikorsky Aircraft, are in the USAF inventory. The helicopter is powered by two T64-GE-7 engines equipped with automatic flight control, engine anti-icing systems, rescue hoist, armor plate protection, armament, external auxiliary fuel tanks and an air refueling system. It weighs 23,324 pounds empty; 37,399 pounds gross. Normal range is 620 miles, and service ceiling is 20,400 feet. Hovering ceiling in ground effect is 11,700 feet. Dimensions are 88 feet in length, 21 feet in width and 24 feet, 11 inches in height. The two T64-7 shaft turbines are rated at 3230 hp each with SFC of 0.485.

SAR HELICOPTER OPERATION PROBLEMS

The HH-53C has serious display/control problems that limit SAR mission success under all-weather conditions. Several reference sources were used to review SAR helicopter operation problems. These include:

- ASD/SDQH 11-45, "ASD Comments on HH-53C PAVE IMP Combat Evaluation Final Report."
- AFFDL-TM-71-2-FGR, June 1971; "SAR Helicopter Problem Assessment."
- IPIS-TN-71-1, April 1971; "Instrument Capabilities Survey, Helicopter PIFAX Program."
- Volume II, "SAR Requirements and Technology Survey," JANAIR Report No. 701220.
- Air Force-Honeywell HH-53C SAR coordination meetings.

Specific hardware problems for the HH-53C have been corrected by the PAVE LOW program. However, the general display/control problems exist and interact with mission success. Several considerations must be kept in mind when dealing with USAF SAR helicopter cockpit design problems and SAR operation problems:

- Helicopter display/control research and development has generally been a low-key effort and has not received the same emphasis as the fixed-wing research and development.
- Traditionally, helicopters have not been flown extensively under conditions that exploit the total capability of the helicopter, i. e., steep-angle approaches. This condition is partly attributable to the fac that most helicopter displays are basically fixed-wing designs with minimum modification for use in helicopters. The result has been low pilot confidence in their ability to fly under IFR conditions.
- All Air Force helicopters are essentially bought off-the-shelf with little if any modifications made. Air Force pilots are therefore forced to utilize equipment developed for other services, which may possibly have unique requirements that adversely affect the SAR mission.
- Pilots tend to discuss control/display issues much more than cockpit arrangement issues. It appears that acceptable displays are a helicopter pilot's prerequisite to an acceptable crew station design.

Many control/display issues were identified in the Honeywell and IPIS and AFFDL/FGR surveys and were confirmed by pilot interviews. The deficiencies of some displays tend to affect the confidence that the pilot has in his whole display system. These control/display issues must be considered for the HH-53C product improvement program. The detail problem issues within the scope of this study include:

- Most helicopter pilots fly VFR using outside references, so helicopter IFR experience is very limited. The limited-night-rescue pilots are probably the most experienced helicopter instrument pilots presently available.

- To fly a helicopter on instruments throughout the complete operation envelope, much higher precision is required for the displays.

- When attempting to utilize conventional instruments in the vertical envelope of the helicopter, several inadequacies appear which affect confidence. Two of these are (1) a reversal error in the attitude indicator at low speeds; the pilot must pitch down and apply power to gain altitude, and (2) airspeed is not accurate below 50 KIAS. What the pilot does is concentrate on outside references for speeds below 50 KIAS.

- Limited night recovery low-light TV tends to cause disorientation when attempting to hover. The twisting, torquing movement, inherent to helicopters, and the visual phenomena present in hover tend to cause vertigo.

- Present doppler and radar altimeters are not accurate enough for IFR hover even with coupler.

- The pitot-static system is drastically influenced by rotor wash, thus providing error-type pressures to airspeed, altimeter and vertical velocity.

- There is no flight director system tailored for helicopters. Unless significant improvements in flight directors are made, confidence in the systems will not be as high as it is with the standard-six configuration.

- When attempting to hover on instruments, the pilot has no real feel for where the horizon is. This is due to the attitude indicator not being horizon stabilized.

- The HH-53C heading indicator is too small and is graduated into 5-degree headings and masked by cyclic stick.

- Fuel management displays are poorly designed and hard to utilize properly.
- On SAR missions the communications task is great, and the intercom control panels should be within easy reach of the pilot and copilot.
- Presently on the HH-53C the copilot performs a dual role. Until established on final approach for a pickup, he monitors all displays, especially those that the pilot is unable to cross-check.
- All hover maneuvers must presently be conducted in a VFR environment.
- A more automatic flight control system is needed in helicopters, but this also increases the requirements for improved failure detection displays.

SECTION IV

ANALYSES

The primary design constraint for the HH-53C avionics configuration for its application to the USAF SAR missions is crew workload. The success of the USAF HH-53C helicopter in satisfying SAR mission requirements depends on the pilot and the copilot being able to operate the vehicle and the avionics to accomplish the objectives of a given mission. The pilot and copilot can be assisted by a wide variety of aids available from our modern technology if they can be used within the requirements and the constraints defined in this study. The majority of the off-the-shelf avionics subsystems have dedicated display(s). Therefore, the more aids installed in the cockpit, the more displays/controls the pilot must monitor. The pilot's primary capability as a decision maker, pattern recognizer, and mission manager has a finite limit. The primary index of pilot/display/control interface has been pilot workload. The trend in cockpit design is that the pilot's workload increases as the complexity and sophistication of the cockpit increases. Thus, the man/machine analysis was conducted to analyze the system requirements and constraints in order to optimize the pilot's performance versus mission and avionics requirements.

The basic system analysis was accomplished in the SAR Joint Services study. That study derived the requirements for the Air Force SAR mission, reviewed the capabilities of the avionic equipment currently available and configured an avionics system for performance and for compatibility with the crew.

The man/machine analysis for the HH-53C was limited to the pilot and copilot stations. The baseline vehicle configuration is the HH-53C PAVE LOW LNRS helicopter. The avionics system is selected from off-the-shelf hardware, all of which have been flight tested. The mission analysis, the functional analysis, the function allocation and the crew workload analysis were reviewed for this study.

FUNCTIONAL ANALYSIS

The purpose of the functional analysis is to select a trial avionics set and to evaluate its suitability for the multimission aircraft. The methods used provide a systematic development of functional requirements which must be met by the avionics complement. The functional requirements were analyzed by determining the parameters necessary for control, for decisions, and for information to the flight crew. The requirements for each function were developed in terms of parameter range, accuracy, speed and relationship conceptually with other parameters. The results of the analysis of functional requirements are long and detailed in nature. They are expressed in terms of classes of functions, which can be summarized briefly as follows.

Flight Control

Flight control functions are those tasks which relate to maintaining the aircraft flight path within a specified envelope throughout the mission phases. The avionics defined is associated with autopilot modes. Three modes were selected for use during the multimissions. A yaw-damper SAS mode is used for takeoff, landing, and low-altitude maneuvering (as in operations 500 feet or less over the water). An attitude-hold CSS mode is used for the cruise phases. A standard flight director system is used for display.

Navigation

Navigation functions include those tasks which must be performed to determine aircraft position in space with respect to desired destination waypoints. Included in navigation are the tasks associated with setting up approach patterns and determining aircraft deviation from command flight path. The study indicated that a navigation computer is required to unburden the copilot during the enroute and search mission phases. LORAN is required to allow updating current position, and doppler is assumed for the backup mode. A projected map display is needed to eliminate position plotting as a flight crew task responsibility. The designation of waypoint data to the computer is predicated on a "SLEW" and "HOOK" capability to avoid most of the requirement for reading and entering digital data by keyboard.

Communication

The communication function is concerned with the transmission and reception of voice-transmitted data (and IFF) both within the aircraft and from the aircraft to ground or to other aircraft. Good usage and procedures are needed to provide a sufficient communications capability to perform the SAR missions. The transmission of data to and from the rescue stations and to and from the front cockpit was not studied in detail.

Systems Monitoring

Systems monitoring tasks are the conventional ones required to evaluate the status of aircraft systems, and functional study results were also conventional. It was found necessary, because of panel space and layout considerations, to replace the usual round instrument group with a more compact vertical-reading display format instrument group.

Search/Mapping

The sensor functional requirements were studied in detail and are described in the Navigation Requirements Analysis subsection.

Command Monitoring

This set of tasks is concerned with the overall conduct of the various phases of the mission and with the coordination of operations within the aircraft. A four-man crew was assumed, with two-place side-by-side seating, and visual and intercom linking was determined adequate for coordination. Sensor displays are provided for the front-seat crew to ensure back-to-front-seat coordination.

Surveillance

The surveillance function includes capability for environmental monitoring by four means. Air-to-air surveillance for other aircraft is considered a visual function, with no need for collision warning systems, since no IFR maneuvering in traffic is described within the missions. The air-to-ground surveillance (other than by the remote sensors) is also considered a visual function. Electronic surveillance for radio transmissions other than the normal guard channels is considered a requirement for these missions. The normal monitoring of frequencies, using the conventional communication equipment, was deemed adequate. Weather radar was not included. Terrain-following radar has some weather detecting capability.

WORKLOAD ANALYSIS

Procedure

Once functional requirements were satisfied by an allocation of tasks to the flight crew members and by the development of the baseline avionics and their functional definition, the analysis proceeded to evaluate individual flight crew member workload. The mission timeline developed in our previous study was used. The crew tasks were analyzed in detail according to the following models:

- Sensing and Perception - The information required for carrying out each task was determined, together with the source of that information. The amount of time required by a human operator to read an instrument, for example, was determined by noting the location of the instrument with respect to the person's eye and by calculating eye-movement time plus eye-dwell time (which is related to the type of display to be read, the amount of information it contains, etc.).
- Information Processing and Decision - The nature of the decisions to be made were detailed and, from these, decision time was estimated for each task. Decision time as a function of amount of information, type of decision, and human information

processing rates are established for many tasks by human factors studies (many of which have been performed at Honeywell).

- Control Actuation Time - The time to reach and manipulate controls were added to the above two times to obtain a total task-performance time. The literature of human factors and industrial psychology (time and motion studies) contain a great deal of data on actuation time that is generally applicable once the relative position and type of control is determined.

By the above models, the time required by a human operator to perform various tasks can be estimated. These times were then used to determine the total time each crew member was occupied by the various tasks allocated to him. The workload criterion is simply that the time required for the total performance of all assigned tasks must be less than the mission time available. The workload estimates depend on (1) the number of tasks allocated to the crew, which of course depends on the degree of automation of the function, and (2) the allocation of tasks among crew members. By several iterations of these two determinants of workload, the minimum workload for a given avionics functional configuration was obtained.

Discussion

One way to evaluate a display/avionic design is to describe it in terms of crew workload versus mission phase. Crew workload is expressed in percent-- the percent of the time available that is required of the crewman to perform the required mission management tasks or the flight-path management tasks. It is generally recognized by the aviation community that under given conditions the helicopter flight-path management task is a higher workload task than the fixed-wing flight-path management task.

The helicopter flight workload is recognized by the Air Force by the statements in AFM 51-13:

> "For instrument flight, it is considered mandatory that two fully qualified helicopter pilots be utilized" for the reasons of:
>
> - "Loss of servo boost
> - Flying in any measurable turbulence
> - Night flying through clouds
> - Vertigo due to rotor and navigation lights"

JANAIR Report No. 680505 (E/O Displays) states:

> "Terrain avoidance is the most exacting of low-altitude flying... Terrain following and terrain avoidance are similar in that they both fly low-altitude profiles parallel to the terrain profiles..."

In the USAF SAR mission a high-workload precision flight task has been added to a basic high-workload vehicle and the crew workload goes to an overload level. Table II estimates the pilot and copilot workload problem for terrain-following flight with the baseline aircraft.

A solution to the workload problem is to integrate the information display, automate the navigation, reduce communication by a revised command and control concept, and, perhaps, improve the AFCS.

Table II. Mission B Average Peak Workload with Baseline Vehicle

Crew Functions	Workload Distribution (%)	
	Pilot	Copilot
Visual Surveillance	20	11
Environment Sensing	--	--
Recovery	--	--
Search	--	100
Communication	16	27
Navigation	--	25
Systems Monitoring	5	--
Flight Control	75	--
Command Reserve	30	30
Totals	146	193

The workload was estimated for an HH-53C baseline vehicle with terrain-following radar based on the Joint Services Study vehicle workload. For the pilot workload estimates, the hypothesis is that:

- The present autopilot is equivalent to the Joint Services study autopilot.
- The pilot's coordination task is increased as reflected by:
  (1) Increased communication requirements - coordination outside the vehicle.
  (2) Increased requirements for coordinating inside the vehicle; increase in command reserve.

Specifically, the pilot's command reserve workload was increased by 10 percent, and 30 percent workload was added to each communication series.

Then the pilot's workload was averaged for a 5-minute period and recorded as shown in Table III.

Figure 5 describes the pilot's estimated workload versus mission time for the baseline vehicle in a terrain-following mode.

A similar procedure was used to estimate the copilot workload. For this workload estimate, the hypothesis is that:

- The search-task workload is increased.
- The navigation update off of radar requires increased attention.
- The command monitor task increases due to the pilot's increased workload.
- Key communication series represent an increased workload (the search task).

Table IV details the copilot workload. Figure 6 shows the copilot's estimated workload versus mission time for the baseline vehicle in the terrain-following mode.

The workload was examined for an integrated system as described in Section V. The hypothesis used to develop the delta workload improvement due to improved avionic displays is that:

- The visual-surveillance-task workload goes to zero in the terrain-following and search modes.
- The communication workload will be reduced to 50 percent of that estimated due to improved communication procedures.
- The command monitor/reserve tasks will be as estimated for the Joint Services SAR study.

The estimated workload improvement with the recommended avionic system is indicated by the dashed-line curves in Figures 5 and 6.

Results

The workload analysis for the recommended avionics set and the panel layout reveal no long-term overloads. High pilot workload occurs at the beginning of a mission phase, takeoff, low-level dash, search, and landing. The flight-control tasks for precise maneuvers to initiate the mission phase occupy the pilot fully. These short-term overloads are, however, considered acceptable and, in the case of a very skilled pilot, may not exist as a problem. In the method used of averaging over 5-minute periods, these peaks do not show up on the curve.

Table III. Pilot Workload Distribution (percent)

Crew Function	Time (minutes)											
	5	10	15	20	25	30	35	40	45	50	55	60
												1
Visual Surveillance	0	0	28	20	20	20	20	20	20	20	20	20
Environment Sensing												
Recovery												
Search												
Communications	24	0	23	18	0	0	0	0	27	12	0	0
Navigation												
Systems Monitoring	0	4	5	5	5	5	5	5	7	3	3	3
Flight Control	0	50	24	18	18	18	18	18	75	75	75	75
Command Reserve	10	26	26	30	30	30	30	30	30	30	30	30
Total for Baseline Vehicle	34	80	106	91	73	73	73	73	159	140	128	128
Total for Recommended Avionics System	34	70	96	81	63	63	63	63	91	79	73	73

Crew Function	Time (minutes)											
	5	10	15	20	25	30	35	40	45	50	55	60
												2
Visual Surveillance	20	20	16	30	20	20	20	20	20	28	36	28
Environment Sensing												
Recovery												
Search												
Communications	0	0	29	24			10		13	7	23	12
Navigation												
Systems Monitoring	3	3	7	4	5	5	4	5	4	5	1	9
Flight Control	75	75	65	35	35	35	35	35	35	47	44	37
Command Reserve	30	30	28	30	30	30	30	30	30	27	30	28
Total for Baseline Vehicle	128	128	145	113	90	90	99	90	102	114	134	114
Total for Recommended Avionics System	73	73	89	71	60	60	64	60	66	74	76	70

Crew Function	Time (minutes)																		
	5	10	15	20	25	30	35	40	45	50	55	60	5	10	15	20	25	30	35
												3							
Visual Surveillance	24	20	20	20	24	20	8	33	20	20	20	20	20	20	20	20	12	0	0
Environment Sensing																			
Recovery																			
Search																			
Communications	16	6	13	7	15	12	0	3	19	0	0	0	0	0	0	0	15	20	
Navigation																			
Systems Monitoring	5	4	4	3	5	6	8	3	9	5	5	5	5	5	5	5	1	7	
Flight Control	37	37	40	65	65	42	61	37	26	25	25	25	25	25	25	25	50	68	
Command Reserve	30	30	30	30	30	30	24	30	30	30	30	30	30	30	30	30	27	26	
Total for Baseline Vehicle	122	97	107	125	137	110	101	106	104	80	80	80	80	80	80	80	115	121	
Total for Recommended Avionics System	80	67	71	77	81	74	70	83	84	70	70	70	70	70	70	70	100	100	

Table IV. Copilot/Navigator Workload Distribution (percent)

Crew Function	5	10	15	20	25	30	35	40	45	50	55	60
Time (minutes)												1
Visual Surveillance	0	55	20	20	20	20	20	20	20	20	20	12
Environment Sensing												
Recovery												
Search	0	0	0	0	0	0	0	0	0	0	0	0
Communications	6	0	0	20	0	20	0	11	19	28	0	0
Navigation	60	20	20	20	20	20	24	30	47	33	33	64
Systems Monitoring	0	0	0	0	0	0	0					
Flight Control	0	0	0	0	0	0	0					
Monitor Command	7	25	30	20	19	19	19	21	40	35	35	29
Total for Baseline Vehicle	73	100	70	80	59	79	63	85	126	116	90	105
Total for Recommended Avionics System	26	37	41	34	32	38	32	30	46	43	42	42

Crew Function	5	10	15	20	25	30	35	40	45	50	55	60
Time (minutes)												2
Visual Surveillance	20	20	16	0	0	0	0	0	0	33	12	20
Environment Sensing												
Recovery												
Search	0	0	30	100	100	100	100	100	100	30	0	20
Communications	14	14	60	11	38	0	24	0	33	28	14	55
Navigation	33	30	46	20	20	20	20	20	20	20	64	20
Systems Monitoring										20	8	0
Flight Control												
Monitor Command	34	34	38	31	24	24	26	24	26	31	26	40
Total for Baseline Vehicle	101	98	190	162	182	144	170	144	179	162	104	155
Total for Recommended Avionics System	42	42	62	62	56	55	56	56	58	44	40	38

Crew Function	5	10	15	20	25	30	35	40	45	50	55	60
Time (minutes)												3
Visual Surveillance	0	0	0	20	20	20	44	20	12	20	20	20
Environment Sensing												
Recovery												
Search	100	100	100	0	0	0	0	0	0	0	0	0
Communications	30	10	28	0	14	50	28	26	0	24	0	0
Navigation	47	20	0	20	30	56	20	20	64	20	20	20
Systems Monitoring	0	0	0	20	12	0	0	0	0	0	0	0
Flight Control												
Monitor Command	18	16	19	33	33	30	34	29	22	21	21	21
Total for Baseline Vehicle	195	146	147	93	101	156	126	95	98	85	61	61
Total for Recommended Avionics System	48	37	20	40	43	40	40	39	36	34	34	34

Crew Function	5	10	15	20	25	30	35
Visual Surveillance	20	20	20	20	46	72	40
Environment Sensing							
Recovery							
Search	0	0	0	0	0	0	0
Communications	20	0	0	24	38	0	0
Navigation	20	20	20	20	20	0	0
Systems Monitoring	0	0	0	0	0	0	12
Flight Control							
Monitor Command	21	21	21	21	34	35	36
Total for Baseline Vehicle	81	61	61	85	138	107	88
Total for Recommended Avionics System	34	34	34	34	41	20	22

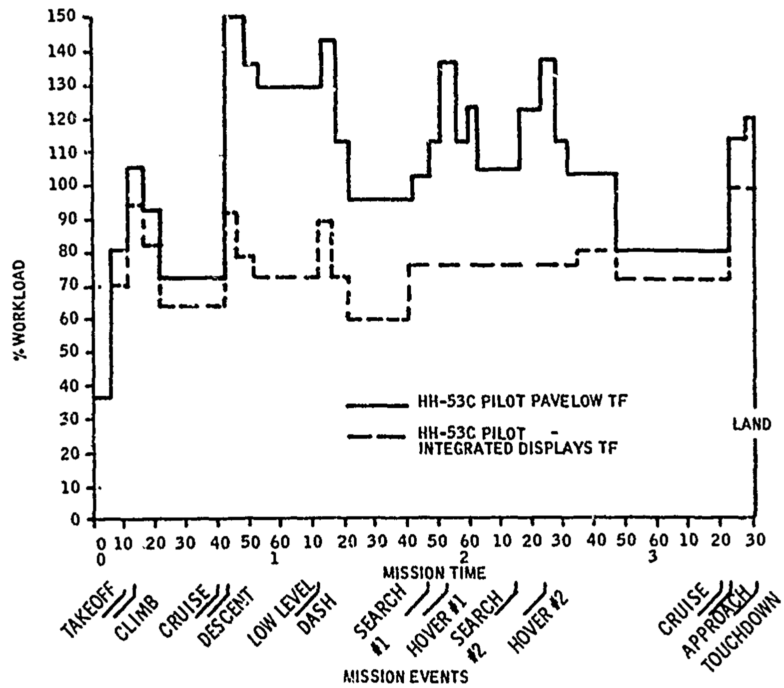


Figure 5. SAR Mission B Pilot Workload

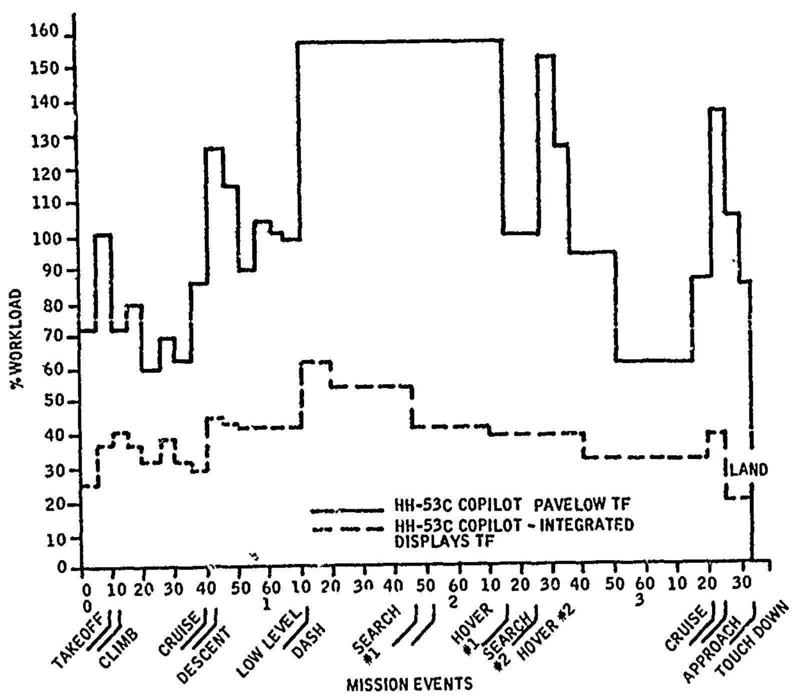


Figure 6. SAR Mission B Copilot Workload

The continuous-terrain-following mission on instruments will undoubtedly generate an accumulation of long-term stress. The effects of this stress, usually described as fatigue, on performance are very difficult to establish. This means that the very highly skilled pilots must be used to minimize pilot fatigue effects upon mission success.

The workload estimates for most of the functions are considered to be reasonably accurate. The exceptions are the flight-control workload estimates. To analyze these accurately is almost impossible because of the effects of aircraft handling qualities and autopilot mechanization on workload. The estimates used in this study are based on simulation results from other helicopter programs.

USAF SAR COMMUNICATION ANALYSIS

Problem

The communication problem is best described by Technical Memorandum AADL-TM-71-2-FGR, dated June 1971:

> "During the rescue approach and pickup, communications is a major problem in SAR operations. From an observation of an actual SAR mission, it is very apparent that the communications tasks in the pickup area are extremely bad. In fact, at times the pilots must turn off all unnecessary radios so that they can concentrate more fully on picking up the survivor. It appears that, as the helicopter approaches the rescue site, everyone in the world wants to know what is going on and what the condition of the survivor is. Any improvement in the communications workload would be a major step forward."

Approach

The SAR communication problems were analyzed by review of documents and audio tapes. Pertinent sections from the following documents were reviewed:

- ASD Comments on HH-53 Combat Evaluation, Final Report
- SAR Helicopter Problem Assessment Report (Burgin and Bondurant)
- Honeywell SAR Study, Final Report, Volume III.

Two tape recordings, supplied by the USAF, were reviewed. One tape was of an actual rescue mission in Viet Nam. The other tape was made on a

training flight during a practice mission. The training mission tape had too much engine noise to be of much value.

Discussion

The data from the documents and the tapes were combined to formulate a concept of the SAR communication problem. Figure 7 describes the problem by illustrating part of the communication links between all of the aircraft involved in the tape-recorded Viet Nam rescue mission. Twelve aircraft were involved. "Lowbird" Jolly Green 03 was actually performing the rescue. "Crown 4" was the rescue operation control aircraft. All the remaining aircraft were giving support, but they each needed specific instructions.

Analysis of the data taken from the tape recordings indicate that the problems cluster into three broad areas as shown by Figure 8 which also indicates the proportion of the total communication problem that each group of problems represent. The procedures problem is the largest, and therefore its solution should yield the most significant results in reducing the crew communication workload. The three problem areas are summarized in the following paragraphs.

Procedural Problems -- The major source of communications problems appeared to be due to lack of procedures -- or possibly lack of following accepted procedures which have been developed over years of military communications evolution.

Too many aircraft were participating -- or attempting to participate -- in the Viet Nam rescue mission. There was much unnecessary radio chatter. Many pilots failed to identify themselves when they initiated calls. The aircraft actually performing the rescue was not guided and assisted sufficiently as it attempted to locate and rescue two downed pilots. The command function did not appear to be as authoritative as the situation demanded.

"People" Problems -- Many pilots spoke too fast and did not enunciate clearly. This necessitated requests for repeats. Explanations were sometimes too lengthy. Human errors in giving directions had to be corrected. Questions went unanswered.

Equipment Problems -- This area appeared to be a minimal source of problems. It may indeed be a major source, but this limited investigation did not reveal it as such.

The helicopter performing the rescue could not talk to downed pilots directly beneath it due to antenna orientation. A microphone switch is required on the hover trim stick. The pilot's and copilot's IC control panels are not located so that both can be seen by each man; moving them to the center

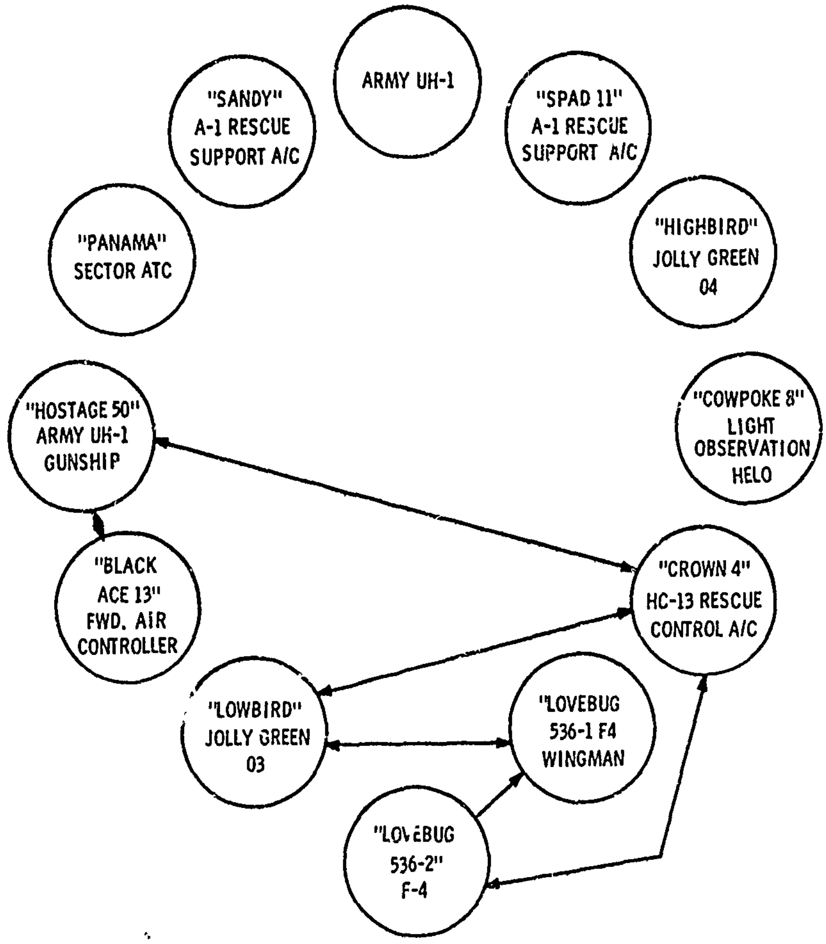
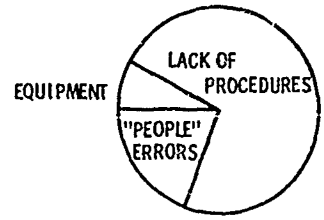


Figure 7. Aircraft Involved in Viet Nam Rescue Operation with Sample Communication Links Shown



EXAMPLES:

PROCEDURE: JG-03-"GIVE ME SOME DIRECTIONS!"

PEOPLE: HOSTAGE 50 - "IS COURSE 210 OK?" (QUESTION ASKED THREE TIMES BEFORE ANSWERED.)

EQUIPMENT: RECEIVING ON ONE CHANNEL WHILE TRANSMITTING ON ANOTHER.

Figure 8. Apparent Communications Problem Areas in the SAR Mission

console would alleviate this. The antenna problem and the microphone switch problem are currently being corrected by an ECP.

Conclusions

Problems appeared most evident in the area of procedures, but there were also some problems due to human errors and some caused by equipment orientation and location.

Establishing and using workable procedures is most important. Through improved procedures, the USAF can make more effective use of the available equipment without designing new equipment.

Radio discipline is important and should be maintained.

The SAR on-site commander's command and control functions need study. Guiding and helping the rescue aircraft must have top priority. The tape-recorded data indicates that basic air traffic control is needed when many aircraft are assisting the rescue effort.

Recommendation

The SAR communication problem should be given serious study in order to better specify the problem.

To improve communication coordination, the pilot's and copilot's ICS control panels should be mounted on the center control panel as shown in Figure 9.

NAVIGATION REQUIREMENTS ANALYSIS

This subsection addresses the problem of defining enroute navigation requirements for a HH-53C helicopter on a search and rescue (SAR) mission. As a result of this analysis, an additional navigation sensor is recommended for the HH-53C helicopter to meet mission requirements. The primary mission requirements are (1) sufficient navigation accuracy for pickup of the rescuee without extensive area search or significant departure from nap-of-the-earth flight and (2) minimization of crew workload. The mission will be conducted under IFR conditions and in mountainous terrain. The rescuee is assumed to possess an active SAR aid for very accurate determination of this position once the helicopter has acquired this transmission.

This evaluation of the HH-53C navigation requirements is based on several deficiencies in the current navigation system that have been identified by

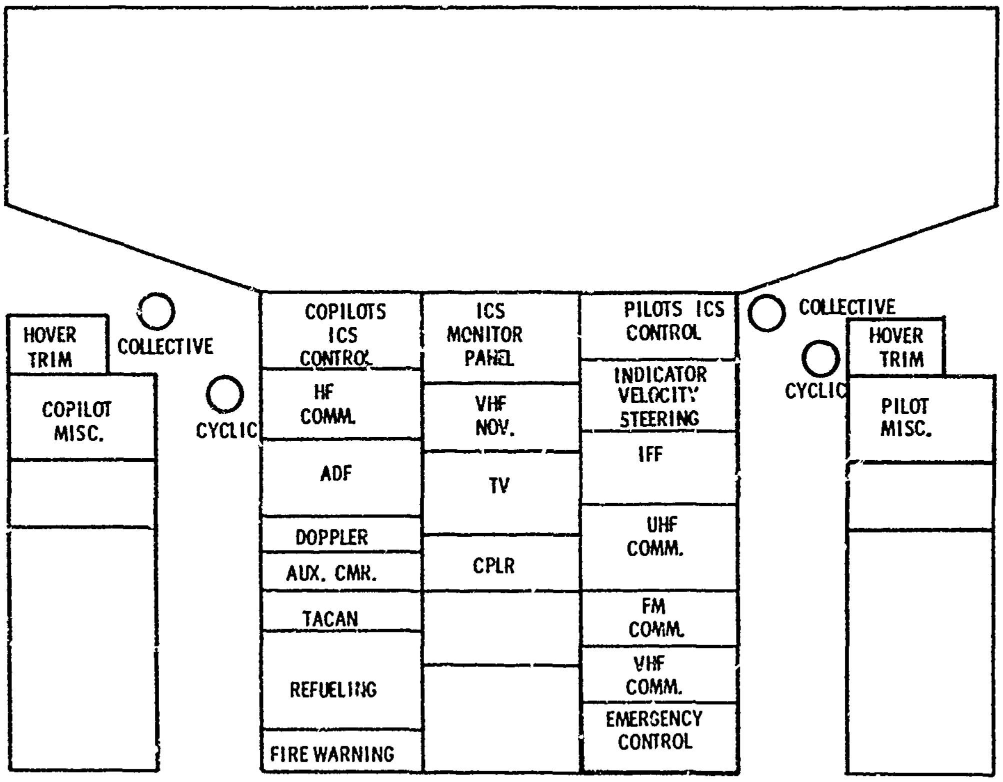


Figure 9. Proposed Arrangement of Communication Equipment

the Air Force as a result of flight evaluation and by Honeywell during the Joint Services SAR study. In general, the deficiencies of the existing doppler navigator relate to (2) inadequate accuracy or (b) excessive workload for the crew. Specific examples of the deficiencies are:

- The crew has difficulty maintaining geographic orientation with respect to the rescuee during low-altitude flight
- The accuracy of the current HH-53C navigation system is not adequate for SAR missions over areas where ground-based navigation aids are not available.
- The crew must perform time-consuming manual coordinate conversions

Scope of Considerations

The mission objective is to direct the HH-53C to the position of the rescuee. The HH-53C will miss the actual position due to errors in the initial position report and the HH-53C navigation system. The position errors were analyzed for the following candidate HH-53C navigation systems and rescuee position-reporting techniques:

- Navigation Systems

  LORAN - AN/ARN-92

  Inertial - LN-12 or equivalent

  Doppler - AN/APN-175(V)-3

- Rescuee Position Reporting Techniques

  Report prior to bailout

  Report from wingman

  Report from airman (LORET)

The rescuee is assumed to possess either ELF or LORET transmitters to aid the recovery process. The primary limitation of these two aids are that line-of-sight must exist between the rescuee and HH-53C. This LOS restriction of the recovery aids requires that the HH-53C pop up to sufficient altitude to obtain LOS at the time the helicopter reaches the predicted location of the rescuee.

Key characteristics of the ELF system are:

- Frequency - 240-285 MHz (line-of-sight-limited)
- Accuracy - ±3 degrees
- Beamwidth - 3 db at ±45 degrees

LORET is a LORAN retransmission system in which a small transceiver receives LORAN signals and retransmits them (unprocessed) on UHF frequencies. These signals may be received by a LORET receiver (UHF command radio) and processed by onboard LORAN (after signal conditioning) to determine the location of the LORET device. Thus, a downed airman may use a LORET device to transmit his position to the rescue helicopter. This position report will be of the same accuracy as LORAN.

The advantages of LORET are highly accurate position reports and low cost. The limitations of LORET are (a) current LORAN systems must be switched from the LORAN antenna to process the LORET thus interrupting the LORAN navigation and (b) a relay aircraft may be required to transmit the line-of-sight-limited LORET position report to the SAR helicopter.

Requirements

The location accuracy required for SAR missions can best be determined by establishing the conditions required to achieve a successful location of the rescuee. Within the line-of-sight constraints described above for the ELF system, the conditions of interest are the relationship between the active SAR aid transmission range and the receiver altitude. Because of terrain irregularities and the need for line-of-sight for transmission, altitude increases with location error for a given degree of terrain irregularity. A plot of transmitter-to-receiver range versus altitude required for line-of-sight existence will therefore establish an altitude/location-accuracy relationship. The impact of the increased altitude needs for low-accuracy navigation systems is longer exposure of the aircraft to ground-to-air threats.

To better illustrate these requirments, Figure 10 shows a downed airman location and the altitude requirements for a series of ground-to-air radio ranges. These radii are a function of the terrain type, the altitude of the receiver, and the probability of line-of-sight, but not the transmitter power. Also shown in the figure are several flight paths through the area, each path representing a given error in locating the downed airman. It can be seen that, for a given location error, there exists a minimum flight altitude for line-of-sight. For this example, line-of-sight will exist for flight paths B and D but not for flight paths A and C.

The functional relationship between line-of-sight probability and flight altitude/range for several terrain classes has been developed in previous

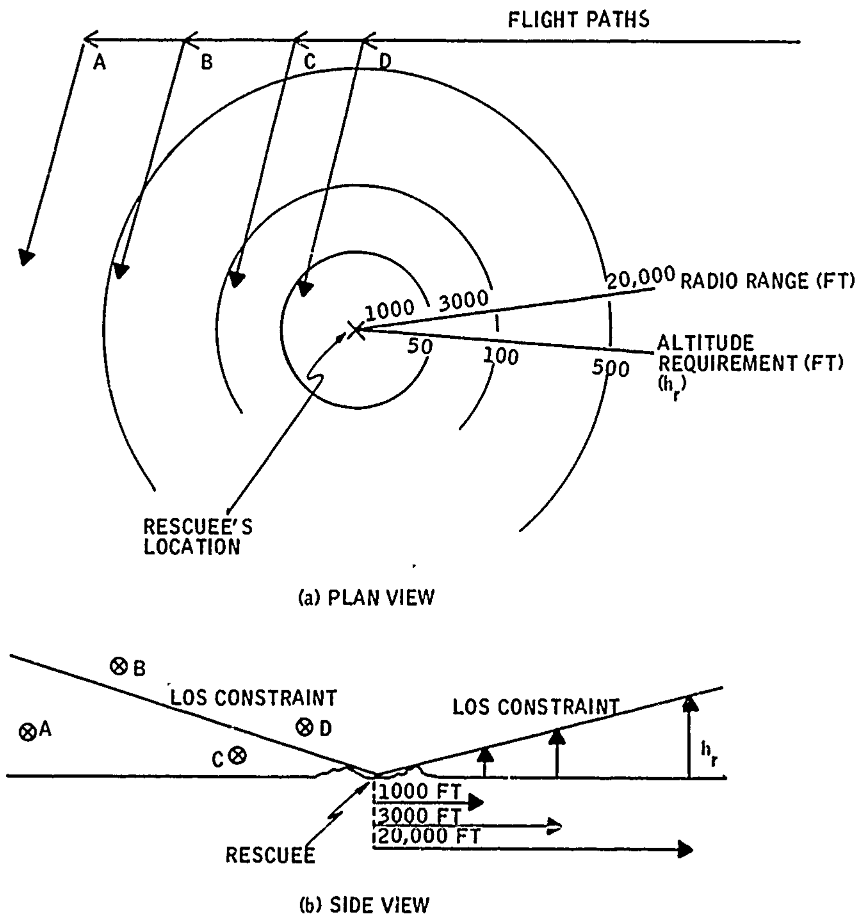


Figure 10. Rescuee Location Accuracy Requirements

Honeywell programs. The data shows line-of-sight probability versus range for a series of altitudes and for several terrain gradients in Europe and Korea. Two sets of severe terrain gradient are used in this study; 200-400 m/km in Korea, and 100-200 m/km in Korea and Europe. The line-of-sight probability requirement is assumed to be 90% to assure success in a large percentage of rescues.

Figure 11 shows the altitude requirements versus location error (range) for the two terrain gradients. For location errors of less than 1000 feet, the altitude is unrestricted so that the helicopter flying a nap-of-the-earth, 50-foot-altitude profile would be successful in receiving signals from the rescuee's SAR aid. At ranges (location errors) over 1600 feet, the helicopter must pop up to assure that line-of-sight between the rescuee and the helicopter is maintained. For ranges (location errors) of over 20,000 feet, the pop up consists of a time-consuming climb with detrimental effects on aircraft survivability.

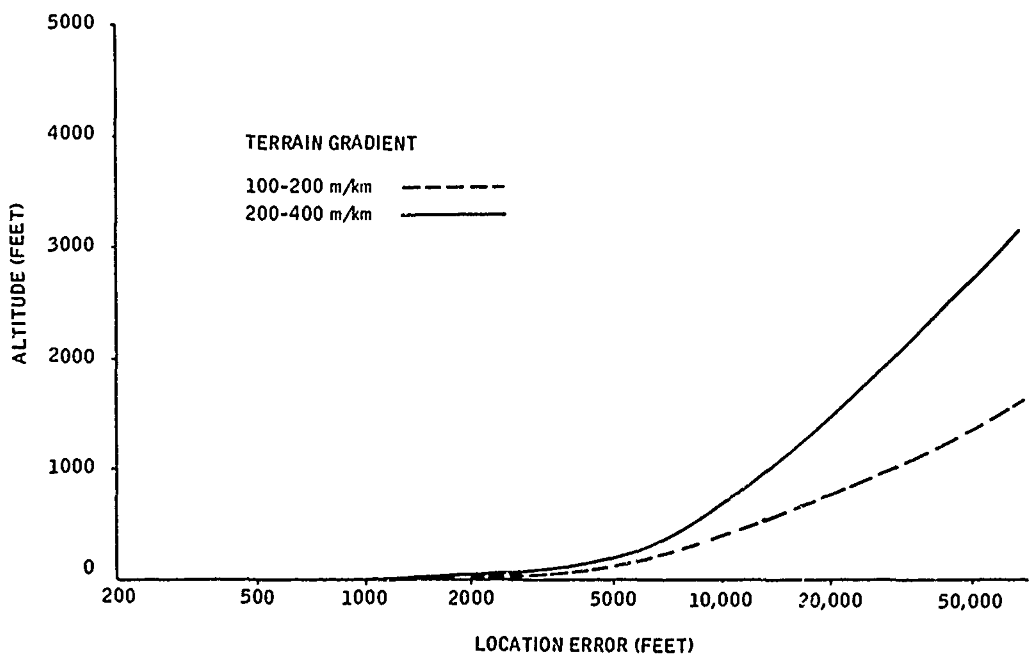


Figure 11. Altitude Requirements for Line-of-Sight Existence

Systems Evaluation

The HH-53C helicopter navigation system alternatives are evaluated on the basis of the flight altitude that is required to obtain line-of-sight (LOS) to a downed airman. When LOS exists between the helicopter and the downed airman, then an active homing system such as ELF can be used to direct the helicopter to the precise recovery point. As discussed above, the altitude requirement is a function of navigation error and terrain type.

The position error in the HH-53C approach to the airman is composed of errors in (1) the reported position and (2) the helicopter navigation system. The magnitude of the position error was estimated for several combinations of report types and candidate navigation systems. The assumptions regarding the accuracy of the alternate navigation systems and report types are summarized as follows:

- Navigation Systems

  (1) LORAN -- The repeatability accuracy of LORAN is assumed to be 1500 feet. The repeatability figure applies to those cases where the helicopter is directed to a position that is based on another LORAN system. The absolute figure is used for those cases where the airman's position is reported in coordinates other tha LORAN.

  (2) Inertial -- The accuracy of inertial systems is expressed in terms of drift (i.e., nm/hr). For moderate-cost inertial systems, performance ranges between 1 nm/hr and 2.5 nm/hr. Consequently, an average accuracy for a typical mission will be on the order of 2 nm.

  (3) Doppler -- Doppler accuracy is expressed as a percentage of groundspeed. Manufacturer's data for the AN/APN-175 specifies a tolerance of 13.75 nm over a 275-nm trip. Test results indicate the actual error is approximately 9 nm. On this basis, an average error over a SAR mission will be 5 nm.

- Position Reports

  (1) Transmission Prior to Bailout -- If the position of the downed airman is based on transmission prior to bailout, then inaccuracies in the position report will be a function of the aircraft navigation system, parachute drift, and the time between the report and bailout. The

position error for this case is difficult to quantify due to the unpredictability of the time between transmission and bailout. However, the position error in this case would be expected to be 2 nm or greater.

(2) Wingman Report -- The accuracy of the wingman's report will be a function of the aircraft navigation system error and the wingman's ability to estimate the offset distance to the airman. The offset position error is assumed to 1000 feet. This error is combined with the error for three candidate navigation systems to arrive at a total error. In the case of LORAN, the repeatability accuracy figure applies if the HH-53C is equipped with a LORAN system. The absolute accuracy applies if the HH-53C is not equipped with a LORAN navigation sensor.

(3) LORET -- If the downed airman is equipped with a LORET transmitter, then the position report will have the same accuracy as the LORAN chain. Because LORET is line-of-sight limited, this transmission must be received by a support aircraft and then transmitted to the HH-53C.

The altitude requirements for line-of-sight for alternate navigation and reporting combinations are shown in Figures 12 and 13. The two terrain gradients represented in Figures 12 and 13 are (1) 100 to 200 m/km and (2) 200 to 400 m/km. If the HH-53C position error relative to the rescuee is less than 1000 feet, then the requirement for LOS will not constrain the helicopters altitude. If the HH-53C relative position error is approximately 2 nm, then an altitude of 400 to 900 feet is required for line-of-sight. If the relative position error exceeds 5 nm, then altitudes in excess of 1000 feet are required.

If the HH-53C is equipped with a LORAN receiver, then the altitude required for LOS existence to the airman can be minimized. As shown in Figure 14, the benefits of a LORAN receiver onboard the HH-53C are most significant if the error in the reported position of the airman is less than 2 nm. On the basis of these results, a LORAN sensor is a recommended addition to the HH-53C avionics. In addition, the doppler navigator should be retained to provide a backup dead-reckoning capability and a velocity aid to the LORAN reciever.

LORAN Description

Based on the evaluation of the navigation requirements for the SAR mission, a LORAN sensor is a recommended addition to the HH-53C avionics. The advantages of LORAN are high accuracy and passive operation from the viewpoint of the receiver. The primary limitations of LORAN are ground-coverage constraints and vulnerability of ground stations.

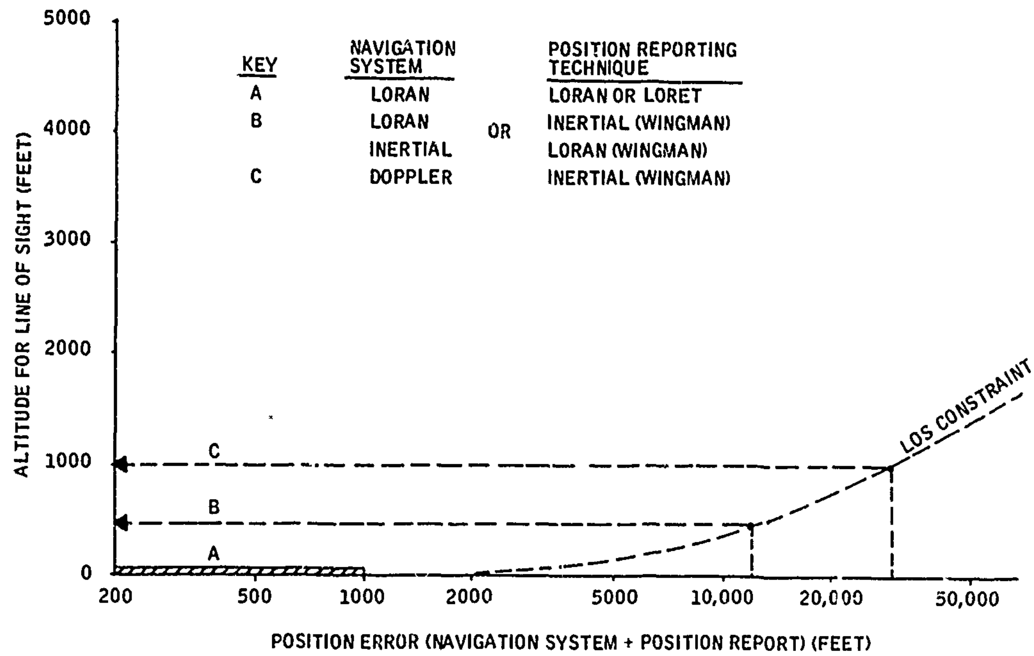


Figure 12. Altitude Requirements versus Potition Error for 100- to 200-m/km Terrain Gradient

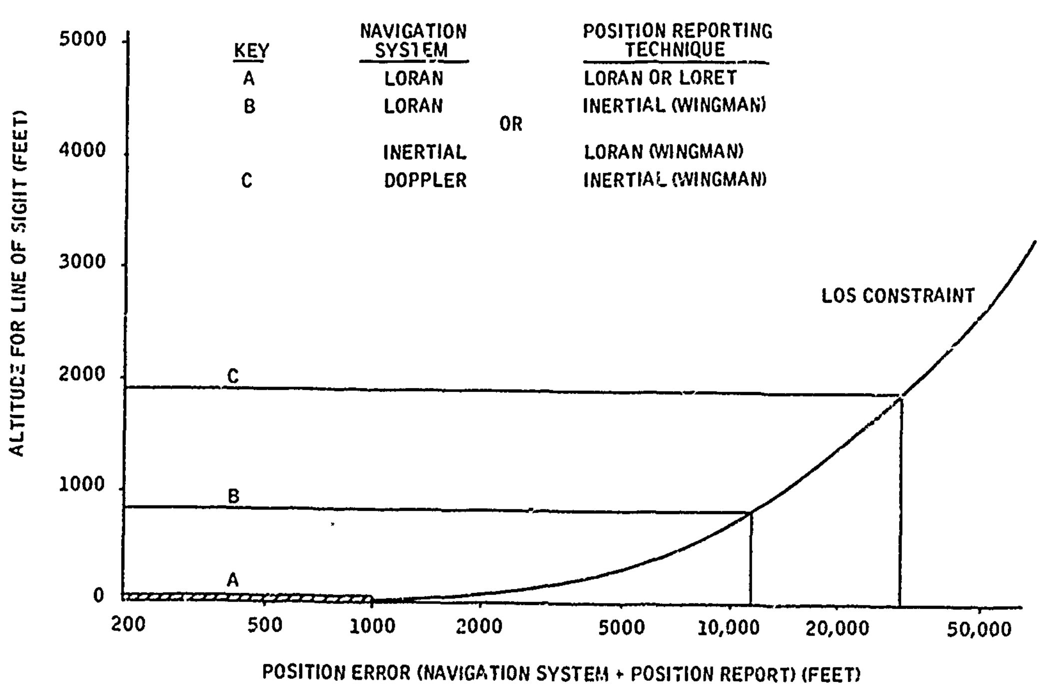


Figure 13. Altitude Requirements versus Position Error for 200- to 400-m/km Terrain Gradient

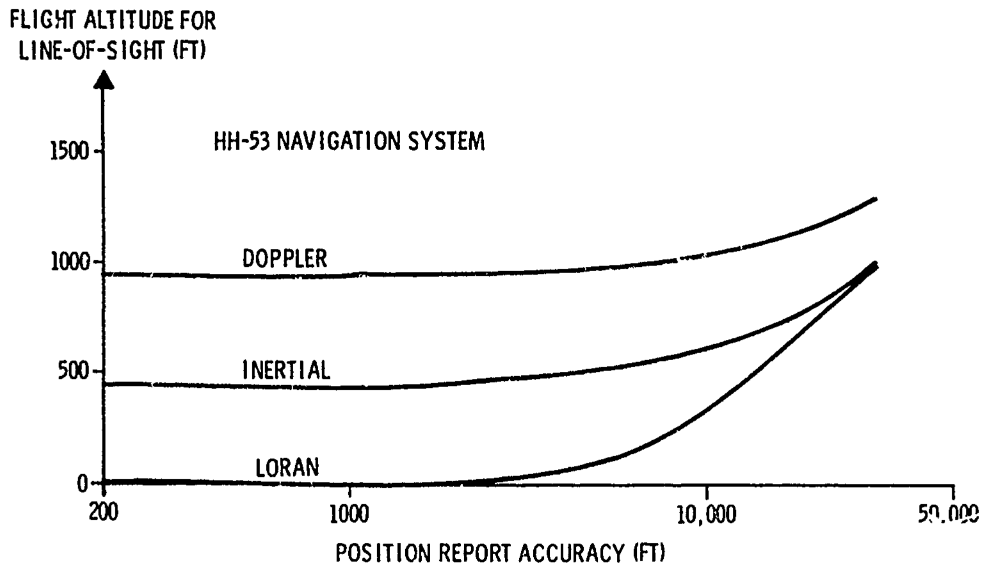


Figure 14. Comparison of Candidate HH-53C Navigation Sensors

Accuracy -- Current LORAN systems provide navigation accuracies of the following order:

- Repeatability:
- Absolute:

The accuracy of a LORAN navigation system is a function of the following factors:

- LORAN network timing
- Atmospheric noise
- Receiver noise
- Grid warpage
- Receiver position with grid (geometric dilution)
- Aircraft maneuvers (receiver backing capability)
- Computational techniques

In addition, LORAN systems are subject to position errors that develop during intervals when the receiver looses lockon or when incorrect cycle identification occurs.

System Description -- An airborne LORAN system will have the following elements:

- Antenna
- Antenna coupler
- Receiver
- Computer
- Control/display unit

The function of the receiver is to acquire and track the incoming LORAN signals. The receiver will include the necessary electronics to implement the tracking loops. The output from the receiver will be time differences.

The computer will perform the following operations:

- Convert TDs to latitude/longitude or UTM
- Compute navigation parameters
- Provide a velocity aid to the receiver
- Select optimum LORAN chain and slave stations
- Accept data insets and receiver control inputs from the control/display unit
- Provide outputs to control/display unit
- Generate receiver control discretes

The control/display unit presents position data to the navigator and allows the navigator to insert data, control the navigation mode, and select the appropriate LORAN chain.

Candidate LORAN Receivers -- A summary description of the characteristics of several candidate LORAN receivers is presented in Table V. Of the candidates listed, the AN/ARN-92 is in Air Force inventory, and the EDO-800 was designed for a helicopter application. For these reasons, the AN/ARN-92 or the EDO-800 are the primary candidates for the HH-53C helicopter. The EDO unit is not compatible with LORAN D and is inherently less accurate than the AN/ARN-92. The compatibility of the AN/ARN-92 with a helicopter environment is not known at this time.

Interface Requirements -- An information-flow block diagram for the AN/ARN-92 is shown in Figure 15.

Table V. LORAN Candidates

Candidate Equipment: Nomenclature	Candidate Equipment: Description	Manufacturer	Unit	Weight (lbs)	Dimensions (in.): L	Dimensions (in.): W	Dimensions (in.): H	Volume (in.^{3})	Unit Cost (X$1000)	Operating Range	Accuracy	Power: In	Power: Out
LR-104	LORAN C/D Nav receiver system	Collins Radio Co.	Receiver	35.5	19.6	7.5	7.6		41.0	Vel: 0-2000 kt	0.05 μs (0.1 μs on cockpit ind)	28 vdc 225 w	
			Control ind	3.4	5.5	5.8	4.5						
			Ant coupler	2.7	10.3	5.8	3.4						
EDO-800	Mini-LORAN A/C	Edo Commercial Corp.		14.0	11.9	11.5	5.1		5.5	Vel: 0-1000 kt Range: 0-1000nm	±3.0 μs	28 vdc 32 w	
EDO-1200	Dual Lok-Track LORAN A/C	Edo Commercial Corp.	Sig proc	24.0	19.6	7.5	7.6		18.0	Vel: 0-2000 kt	±3.0 μs	115 vac 80 w	
			Cont box	2.0	4.1	5.8	4.1						
			Indicator	4.5	12.7	3.8	3.8						
AN/ARN-92	LORAN C/D Nav system	ITT	Receiver	36.5	17.6	7.5	7.6		85 (for 50) 80 (for 150)	Vel: 0-2000 kt	0.025 μs	115 vac 28 vdc 5 vac Rcvr, cont-I and ant coup 425 w; comp 135 w	
			Cont ind	10.0	6.5	5.5	9.0						
			Ant coupler	1.5	5.3	1.7	3.8						
			Computer	48.0	23.4	10.8	7.8						
AN/APN-181	LORAN C/D Receiving system	ITT	Receiver	38.5	17.6	7.5	7.6		45 (for 50) 40 (for 150)	Vel: 0-2000 kt	0.025 μs	115 vac 300 w 28 vdc 12 w	
			Cont ind	5.5	5.1	5.8	8.6						
			Ant coupler	1.5	5.2	1.7	3.7						
AN/ARN-78	LORAN C Receiving system	Sperry	Receiver	26.5	22.6	4.9	7.6			Vel: 0-2000 kt	0.1 μs	115 vac 143 w 28 vdc 12 w	
			Cont ind	0.9	5.8	5.0	6.0						
			Cont rec	2.9	2.6	5.8	6.0						
			Ant coupler	4.0	7.8	8.0	3.3						
AN/ARN-85	LORAN C/D Receiving set	Sperry	Receiver	23.7	22.6	4.9	7.8			Vel: 0-2000 kt	0.1 μs (C) 0.05 μs (D)	28 vdc 180 w Optional 115 vac 180 w 28 vdc - 2w	
			Cont ind		6.5	5.3	9.0						
			Ant coupler		7.8	8.0	3.1						
			Ind coupler	15.0	16.3	4.9	7.6						

Nomenclature	Operating Modes	Temperature Range (°C): From	Temperature Range (°C): To	MTBF (hrs)	Sensitivity	Noise	Bandwidth (kHz)	Frequency (kHz)	Comments
LR-104	Off, PRR, ATD, BTD, track	-55		1000 est	5 μv/m field	S/N = -20 db			Self-test; automatic search, lock-on and tracking
EDO-800	Power off, on, delay int	-15	+55	Design 2000	1 μv/3/1" deflection		7 at 6 db	100	Designed for general aviation, auto tracking
EDO-1200	Off, ch. 1, 2, 3, C, Cs	-15	+55	Design 5000	0.5 μv		14	100	Airline version of AN/APN-180; independently and simultaneously track 2 different LORAN rates
AN/ARN-92	Off, standby, LRN, DOP/INS, DR	-54	+71	200	0.5 μv	S/N -20 db	Track: 20 Search: 5	100	Computer described under Nav Computer Matrix; automatic search and track
AN/APN-181	Off, standby, on	-54	+71	300	0.5 μv	S/N -20 db	Track: 20 Search: [illegible]	100	Auto search and track
AN/ARN-78	Off-on	-54	+55	25	5 μv	S/N -20 db	23	100	Auto search
AN/ARN-85	Off-on	-54	+55	50	5 μv	S/N -20 db	(C) 23 (D) 16	100	Can be used independently or in conjunction with AN/ARN computer (see Nav. Computer Matrix)

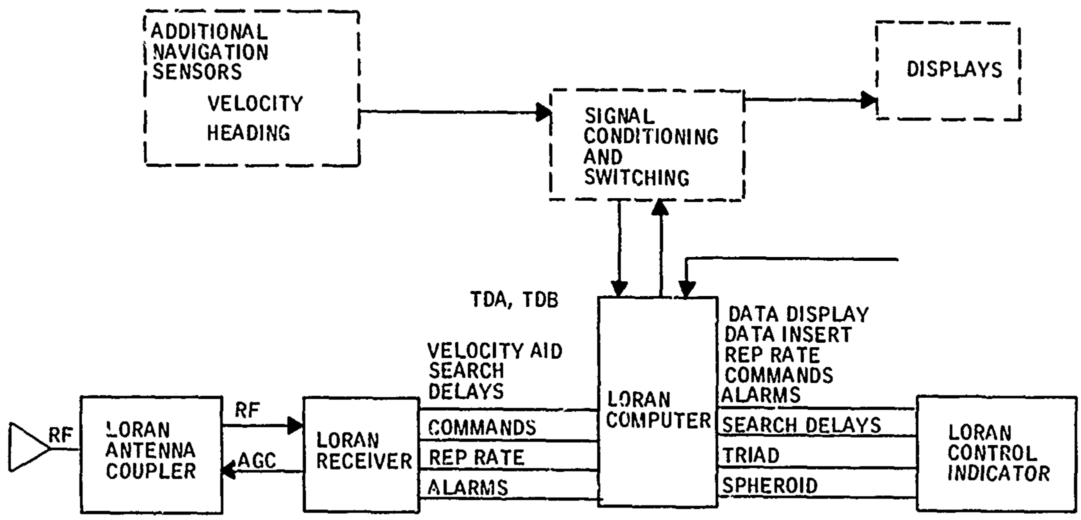


Figure 15. LORAN Sensor Information-Flow Block Diagram (AN/ARN-92)

Computational Requirements -- The computational requirements for the functions listed above are summarized below in terms of memory, instruction mix, and iteration rates.

To perform the LORAN functions, approximately 4K of computer memory is required. To meet resolution requirements, double-precision arithmetic will be required for 16- or 18-bit word-length computers.

The processing time requirements are primarily a function of the TD to latitude/longitude computations. The instruction mix for one iteration is:

- Add - 55
- Multiply - 60
- Divide - 15
- Trig - 15

This instruction mix is based on an algorithm that updates latitude/longitude by:

- Predicting the next set of TD values based on the present position estimate
- Comparing the predicted TDs to measured TDs
- Updating the latitude/longitude estimates on the basis of the TD difference
- Iterating the above process until the TD difference is within resolution limits.

Generally, one iteration is satisfactory for each set of incoming TDs for normal LORAN pulse-repetition rates. LORAN pulse-repetition rates range between 10 and 25 times per second. Consequently, the maximum number of instructions to be executed per second will be on the order of:

- Add - 1375
- Multiply - 1500
- Divide - 325
- Trig - 325

For helicopter applications, lower iteration rates may be acceptable due to the HH-53C speed range.

NAVIGATION MANUAL-FIX PERFORMANCE ANALYSIS

This subsection provides an analysis of errors in the navigation equation and subsystem that are introduced by using a ground-mapping radar and processing of the radar video to update a helicopter navigation subsystem. The radar system chosen for this analysis is a phase-comparison off-boresight unit. Errors introduced into the navigation system using the APN-141 radar and the errors associated with the data processing required are examined, and an evaluation of the navigation system accuracy is derived.

Off-Boresight Radar

The APN-141 is an off-boresight phase-comparison radar (phase interferometer). It is designed to obtain wide enough elevation coverage without mechanical scanning for a terrain-avoidance/following mode in subsonic aircraft. Use of the off-boresight phase-comparison processing for terrain elevation also make the radar less susceptible to rain clutter. The problem associated with this type of scan is that, out to minimum range, precipitation echoes predominate, and these precipitation echoes will be interpreted as a terrain profile extending from the aircraft forward roughly along the center

of the antenna elevation pattern. For this reason, returns must be gated off out to the minimum range. The off-boresight phase-comparison radar has an effective coverage in elevation that extends beyond 30 degrees below the horizontal. Minimum range (R_M) is thus less than twice the aircraft altitude in flight over flat earth, and it is practical to gate out echoes received from ranges out to R_M on the basis of altimeter measurements with respect to the terrain under the aircraft. The sensitivity of R_M is about 3% per degree of slope.

For the present application the nominal blanking range would then be about 400 feet in flight at a 200-foot attitude.

In a phase interferometer system, the angle of arrival of the radar echo at any instant is measured in terms of the phase difference between the echoes arriving at two antenna arrays placed one above the other. The array centers should be separated by one-half wavelength. The phase interferometer technique is present state-of-the art, having already been proven in several different systems. The basic angular measurement accuracy against distributed terrain at shallow incidence angles, is about 0.25 degree. Allowing for stabilization errors, random bias errors, and mounting-surface alignment errors, the accuracy is still good to 0.50 degree.

In a phase-comparison system, the instantaneous terrain-return elevation angle information is contained in the relative time displacement of the zero crossovers of the RF and IF waveforms of the two receiver channels. By hard limiting in successive amplification stages, distortion in relative timing of these zero crossovers with variation in signal strength is suppressed and good performance is achieved over a terrain echo dynamic range of 80 db.

Factors Affecting Radar Accuracy

Range Accuracy -- Several factors affect the accuracy of a radar system being used to update the navigation system. These include, for range measurements:

- Digital resolution
- RF source jitter
- Signal-to-noise ratio
- Frequency stability
- Operator ability and display resolution

The first four factors are related to the radar mechanization directly, while operator ability and display resolution are a function apart from the mechanization of the radar and will be discussed in a later section of this analysis.

Digital Resolution -- If range is measured within the radar with a binary counter, the range measurement is quantized in increments the size of which depend on the clock rate used. A 10-MHz clock rate gives a RMS error figure of 15 feet in range measurement.

RF Source Jitter -- An uncertainty in the zero-range time occurs if there is a variation in time between the trigger provided to the RF source and the main band. Proper design techniques can hold this uncertainty to 5 feet RMS.

Signal-to- Noise Ratio -- With a low signal-to-noise ratio (S/N) the leading edge of a target return varies, making it difficult to properly measure the exact time of the return. However using a phase interferometer where elevation is measured by phase comparison techniques, hard limiting can be used in processing; thus accurate measurements can be made over a large dynamic range signal. For this analysis a range error of 30-foot RMS is assumed. This magnitude of error is based on the equation found in Sbolnik - Introduction to Radar Systems (page 468). The equation is given for calculating range error as a function of S/N. The 30-foot RMS is based on a transmitted pulse width of 200 nanoseconds and a receiver bandwidth of 10 MHz.

Frequency Stability -- The frequency instability of the clock oscillator for the range measurement introduces an error proportional to range. A stability of 1 part in 10^4 is assumed for this analysis, which gives an error equal to 0.6 ft/nm of range.

Error Calculation -- For range accuracy, the RMS value for several different ranges is calculated and recorded as follows:

Range (nm)	Range Error (ft)
2.0	34.2
5.0	33.8
10.0	34.5
20.0	36.0

The above errors are a function of the radar mechanization. A more significant error will be associated with operator ability and scope resolution. For this analysis it is assumed that the range and azimuth presentation is on a PPI presentation which is a 4-inch scope. In range, the radar can be operated from 2.5 nautical miles at a 200-foot altitude to a maximum range of 36 nm at pop-up altitude. Accuracy of this measurement parameter is examined over the range of 2.5 to 25 nm.

The width of the crosshair is assumed to be 0.01 inch in the scope, and the operator in the helicopter environment is assumed to be able to align the crosshairs with a 0.05-inch accuracy. Survey of the literature has shown

that, under very smooth conditions in a fixed wing aircraft, it can be aligned within 0.01 inch. Under worst conditions in a helicopter, the alignment may be as bad as 0.1 inch. With the above limitations, the range accuracy for the several ranges is:

Range (nm)	Range Error (ft)
2.5	60
5.0	96
10.0	192
15.0	288
20.0	384
25.0	480

Assuming that the operator can align the crosshairs to an accuracy of 0.05 inch RMS with the leading edge of the target, the resulting RMS range error is approximately 60 feet at ranges less than 2.5 nm and approximately 0.3% of range beyond 2.5 nm.

A comparison of the two error listings shows that the major component of range error in updating a navigation system is contributed by the capabilities of the operator and the display on which he locates the update fix.

Azimuth Accuracy -- Several factors also affect the azimuth-measurement capability of a radar for position updating. These factors include:

- Electrical boresight error
- Radome deflection
- Mechanical alignment
- Encoder resolution
- Encoder alignment
- Signal-to-noise ratio
- Operator ability and display resolution

For the azimuth accuracy analysis, errors typical of those associated with a phase-difference radar such as the APN-141 were assumed. These factors were taken from the literature and are:

• Boresight error	2 milliradians RMS
• Radome deflection	2 milliradians RMS
• Mechanical alignment	1 milliradian RMS
• Encoder resolution (11 bits)	10.5 minutes resolution
• Error	3.0 minutes RMS

- Encoder alignment 1.5 minutes RMS
- S/N (5 db) 0.22 minute RMS
- Operator ability 12.0 minutes RMS
- Stabilization (pitch and roll) 1.0 minute RMS

Figure 16 shows the azimuth error of the radar for various signal-to-noise ratios. For this analysis an S/N of +10 db was used assuming that the range of the radar at a 200-foot altitude would provide very strong returns higher than +10 db and that returns from extended ranges during pop up would probably be in excess of 0 db.

Figure 17 shows expected azimuth error versus slant range calculated using the parameters previously described. At extreme ranges the predominant error again is the operator capability and display resolution since very large areas of ground are being covered with a small display. At the nominal operational level of 200 feet, azimuth errors will be on the order of 50 feet.

Geometry Errors -- The cursor command is proportional to the slant range to the designated point on the display. To determine the exact ground distance separating the aircraft nadir point and the checkpoint, it is necessary to determine the length of the corresponding arc on the surface of the earth. As an approximation to the arc distance, the horizontal range, R_h, is computed. This approximation significantly simplifies the computation procedure and is based on the use of a tangent-plane coordinate system. The magnitude of the error resulting from the use of this approximation is investigated below. Figure 18 shows an exaggerated view of the geometry for this situation.

The analysis task is to determine the difference between R_h and S at the maximum radar range. The error will be greatest at this point. The maximum radar range considered is 24 nm. The value for $\Delta\theta$ at this range is approximately 1.1 milliradian. To achieve a range of 24 nm, an aircraft altitude of approximately 160 feet is required.

The following relationships exist between the variables in Figure 18:

$$R_s = R_e \tan(\Delta\theta)$$

$$S = R_e (\Delta\theta)$$

If the tangent function is approximated by the following series:

$$\tan(\Delta\theta) = \Delta\theta + \frac{(\Delta\theta)^3}{3} + \frac{2}{15} (\Delta\theta)^5 + \ldots\ldots$$

then the difference between R_s and S is approximated by

$$R_s - S \approx R_e \frac{(\Delta\theta)^3}{3}$$

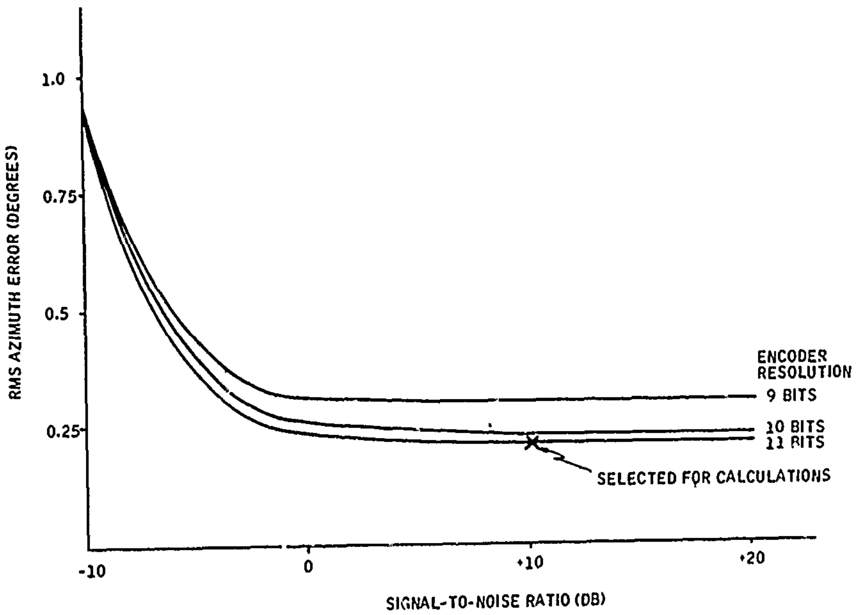


Figure 16. Azimuth Error versus Signal-to-Noise Ratio

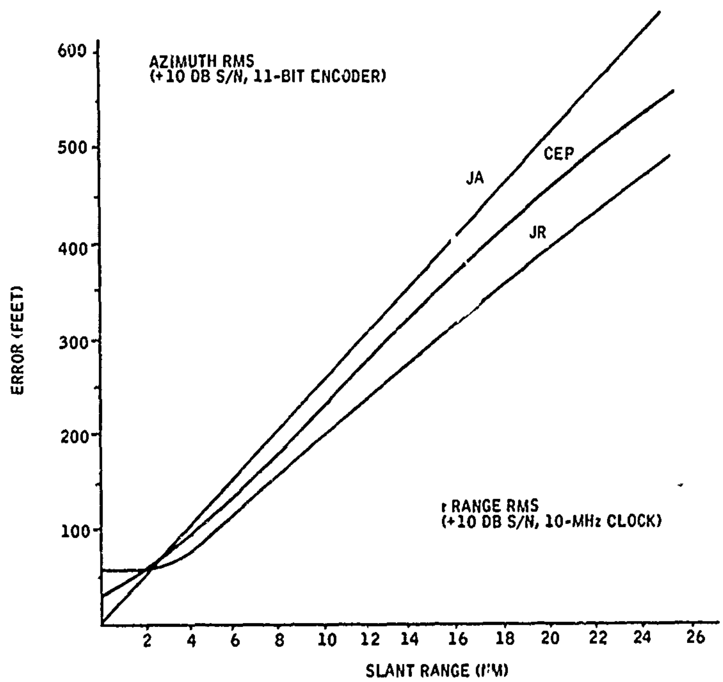


Figure 17. Expected Radar Error versus Range

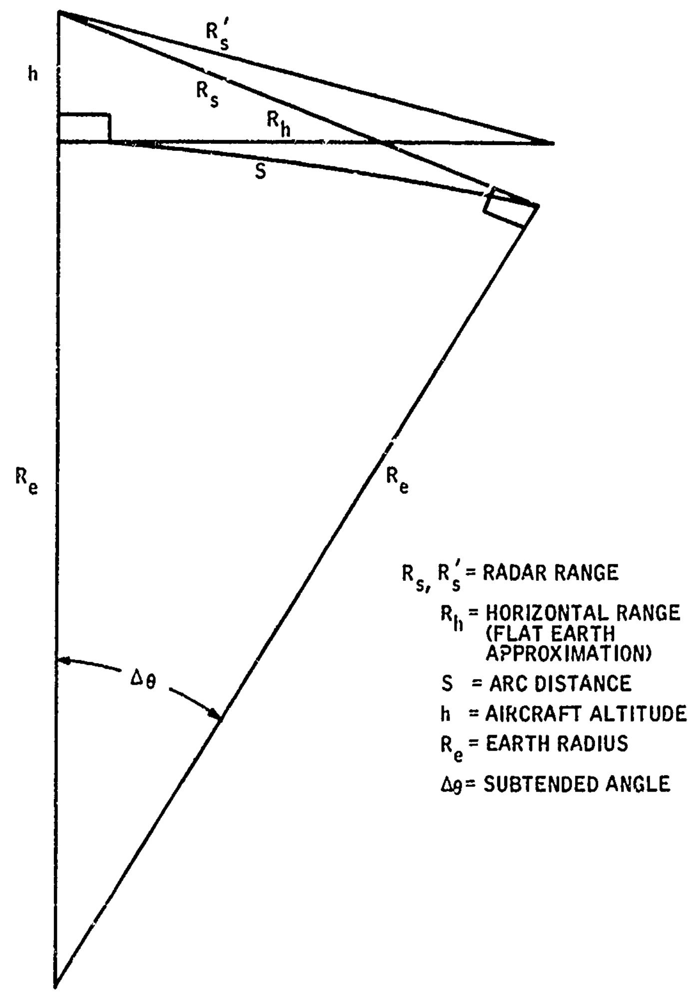


Figure 18. Tangent Plane Geometry

At a range of 24 nm, this difference is

$$R_s - S \approx (2.1 \times 10^7) \frac{(0.0011)^3}{3}$$

$$\approx 8.9 \text{ ft}$$

Examination of the total error caused by earth radius shows that at a maximum range of 24 nm the error contributed by this factor is insignificant when compared to other errors and can be neglected in calculating update capabilities.

Using the above calculations and the CEP curve from Figure 17, it can be postulated that the ability of a radar operator to update a navigation system by the use of the APN-141 radar would be reasonable if it is assumed that there are known radar targets within an approximate 10-nm range. With a CEP of 200 feet for a target at approximately 10 nm the continuous accuracy of a navigation system could be described by Figure 19.

Figure 20 shows the curves for current inertial/doppler navigation systems and describes the accuracy of the 0.5-nm/hr and the 1.0-nm/hr navigation systems.

Terrain Following Using Existing TV Monitor

The investigation of terrain-following capabilities using the APN-141 radar also included an examination of the display requirements for the Norden shades-of-gray terrain-following display. As originally implemented, the Norden display required a roll yoke (mechanical) for display stabilization as the aircraft rolled. This dictated the need for a special display to present the APN radar video when used in the terrain-following/terrain-avoidance mode.

The current configuration of the APN-141 radar provides for roll stabilization electronically so that the stabilized display can be presented on any standard airborne CRT monitor. Investigation of the video processing for the APN-141 radar shows that the video can be displayed on the existing CONRAC airborne monitors which provides a raster mode of presentation and are capable of presenting multiple shades of gray to represent the terrain contours provided by the APN-141.

No major adaptation need be made to the CONRAC monitors to display the information generated by the APN-141 subsystem.

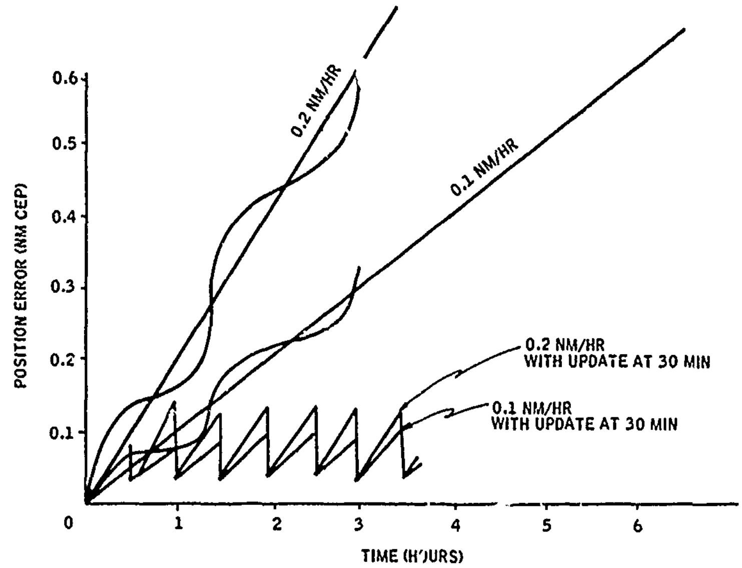


Figure 19. Position Error versus Time for High-Accuracy Systems

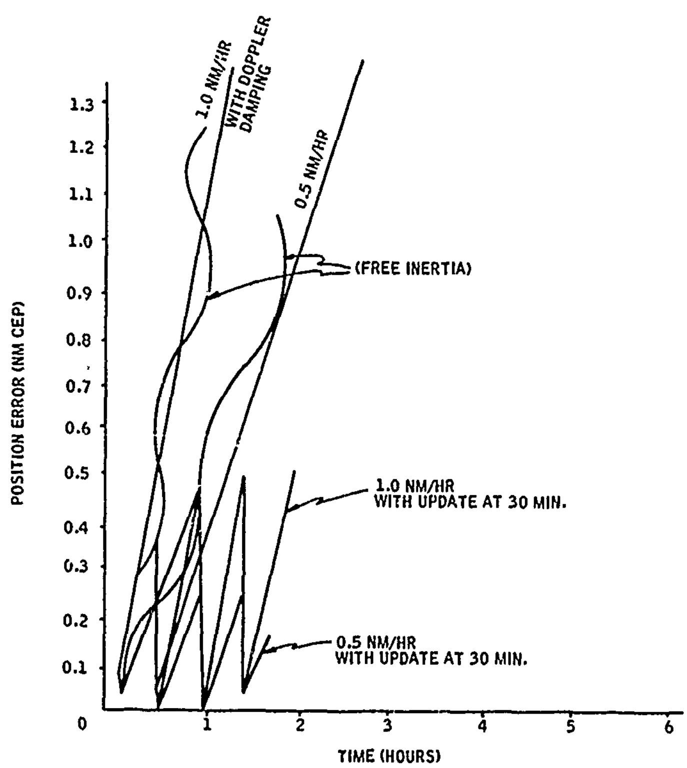


Figure 20. Position Error versus Time for Current Systems

Terrain Following Using LLLTV

Currently the low-light-level TV is capable of providing a very good picture to a pilot of the terrain which is ahead of his vehicle, under very-low-light-level conditions. This information can be useful to a pilot in terrain following or terrain avoidance, but a LLLTV presentation is not sufficient information to fly either terrain following or avoidance since the presentation does not provide the third, or range, dimension needed to allow for aircraft control and response.

LORAN - OMEGA Compatibility

A study of the LORAN C/D navigation subsystems and the OMEGA navigation subsystem shows that, even though they are both essentially low-frequency hyperbolic systems, the basic equipments are not compatible and would not be easily modified to provide processing for both. If both LORAN and OMEGA navigation systems were available, a single control panel for selection of the system and input of data as required, as well as a single display type, could be used for both.

The major incompatibilities in the systems are in the RF and data-processing equipments. The LORAN system operates at 100 kHz with all energy within the 90- to 110-kHz band. The OMEGA navigation system is also a long-range system which operates in the range of 10- to 14-kHz. Pulse spacings of master and slave stations are also different for LORAN and OMEGA. These differences in basic equipments preclude, at this point, modification to adapt one navigation system to both types of signal input.

AFCS REQUIREMENTS ANALYSIS

The correction of deficiencies in the present AFCS modes and the addition of specific new modes to improve SAR mission capability were studied. Two principal deficiencies, heading hold looseness in the transition to hover, and hover mode drift, require improvement. Specific system change recommendations to tighten the heading mode will require an analysis based on detailed dynamic definition not available for this study.

The hover mode requires a position-loop closure to eliminate the drift characteristic of the present velocity loop. The addition of the ELF system to the aircraft provides a suitable position signal source. A coupler would be needed.

Added AFCS capability can be obtained by a coupler to provide automatic homing on the rescuee during the approach, using the ELF azimuth direction signal for steering. Further improvement is possible by coupling to a navigation heading-error signal.

All of the performance possibilities of any improvement are necessarily limited by the basic AFCS inner-loop responsiveness. It is therefore necessary that the aircraft-AFCS dynamics be determined as a first step in any upgrading plan.

Background

The AFCS in the HH-53C is important to the SAR mission first for it's potential to improve aircraft handling characteristics and second by it's capability of reducing pilot workload by performing automatically certain phases of the flight. The evidence by which the performance of this AFCS was judged were reports of flight control problems that have been experienced by pilots. These accounts indicated that some deficiencies, such as an altitude-hold oscillation, have been successfully corrected and others, such as the hover trim hysteresis, are slated for correction.

Two remaining principal problems were identified:

- Heading-hold wander
- Hover drift

No specific mention of suboptimal performance of the other automatic control modes was identified. This was interpreted as evidence of satisfactory performance. It is recognized, however, that, particularly in the case of the extremely cross-coupled nature of the four basic control loops of a helicopter, improvements in any axis may be limited by the dynamic behavior of the others. Further, the performance limits of additional control modes may be limited by the response characteristics of the basic inner stabilization and servo mechanizations.

System Deficiencies

Heading-Hold Problem -- Difficulties were reported with heading-hold performance during the transition from approach to hover. First, the heading varies, under the variable torque disturbances, to the extent of causing loss of target on the LLLTV. Secondly, the motion is sufficient to cause vertigo from the image motion on the LLLTV. A ±1-degree heading-hold ability is required to avoid these difficulties.

The heading AFCS loop, (Figure 21) is mechanized with a compass gyro signal as the attitude-error source controlling the tail rotor pitch-angle servo valve. A damping signal is added from a yaw-rate gyro. Lateral accelerometer and roll-rate gyro signals for turn coordination are added at airspeeds above 60 knots in turning maneuvers and are not involved in the yaw control under the problem conditions at approach to hover.

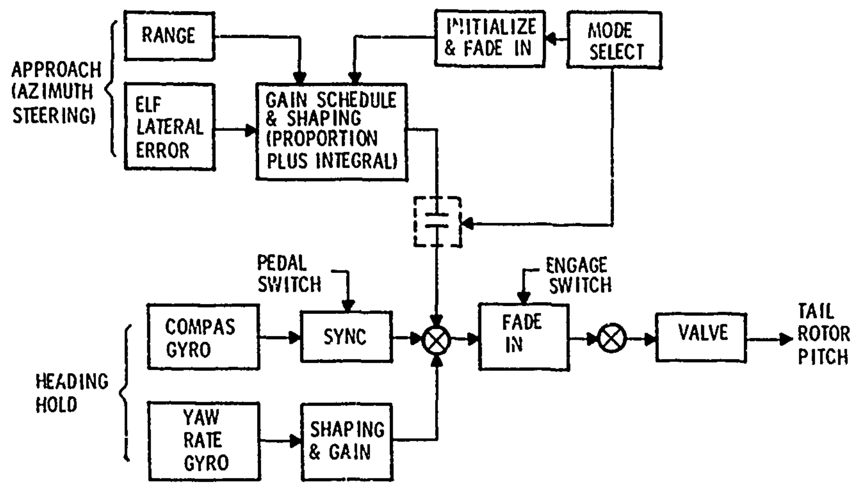


Figure 21. Yaw Channel Homing with ELF Tie-in

The basic sensor, shaping, and summing elements for heading hold are present. It can be expected that the system gain, and therefore accuracy, has been optimized as far as the limits of the system elements will permit. In such cases, dynamic limits are generally found to result from nonlinearities such as friction, backlash, deadbands, and torque or other authority limitations. These characteristics are not defined at the level of system definition available.

The gyro compasses, MA-1 or J-4, are capable f sufficient sensitivity for the the ±1-degree requirement. However, their compensation (or lack of it) for roll- and pitch-attitude changes may contribute to heading-hold deficiencies.

The sensor response characteristics are likely to be adequate, but the existence of the yaw-axis damping in that servo may limit heading-hold response to disturbances.

The present total AFCS tail rotor authority may also turn out to be performance limiting.

Corrective measures required to achieve ±1-degree heading-hold accuracy require an analysis of the system based on a more detailed description of the system's dynamic elements.

Hover Drift Problem -- The automatic hover system has a drift characteristic that requires manual trim updates to hold a hover position. It is recognized that the trim system hysteresis problem is being corrected. While this may improve the ability to hold position and therefore ease the task somewhat and improve performance, the manual trim will require continual crew attention and depend on an ability by some means to see the hover position.

The principal input signals to the roll and pitch axes for the automatic hover mode are radar navigator velocity signals. A lateral accelerometer signal is also used in the roll axis. Each axis, of course, has a trim signal input. The dynamic treatment of these signals is undefined and is represented by the transfer function blocks K_n in Figures 22 and 23.

The limit of the ability of the automatic mode to hold position is set by the zero-rate threshold of the doppler input. It will never be drift-free without a position-type signal into the system. With an ELF system, the lateral and fore-and-aft signals can be used to provide a displacement signal to the lateral and pitch axes in hover.

These signals are beam, or diverging, type signals and may require altitude-gain scheduling to optimize gain for varying hover altitudes. In addition, it can be seen that accurate zero-offset hover will require an integral feed forward on this signal. It will probably be prudent to provide a hover trim bias signal for accurate offset positioning of the hoist or otherwise to provide operational flexibility of the system. For a functional diagram of the tie-in of these features, see Figures 22 and 23.

Hover-drift elimination requires a position-type signal input to the roll and pitch axes. The ELF system signals can provide such a signal. The operational performance of such a system will depend on sensitivity, stability, and thresholds of the ELF signals as well as the performance of the present AFCS attitude-hold and hover mechanizations.

Added Capability Problem

Auto Homing Mode -- Locating the rescuee exactly from a position within the range of a location sensor such as ELF may be considered for a completely automatic control. It is recognized that the altitude and velocity profile to be flown is critical to this portion of the mission. However, it is assumed that the performance of the present mechanization is adequate for descent and deceleration, as no specific complaints were disclosed. Therefore, this discussion is limited to the azimuth steering portion of the homing phase of the mission.

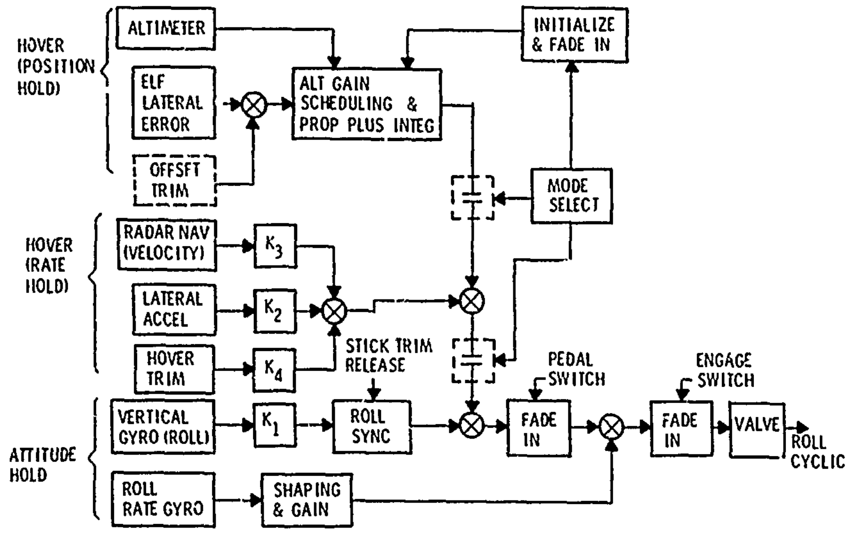


Figure 22. Roll Channel Hover with ELF Tie-in

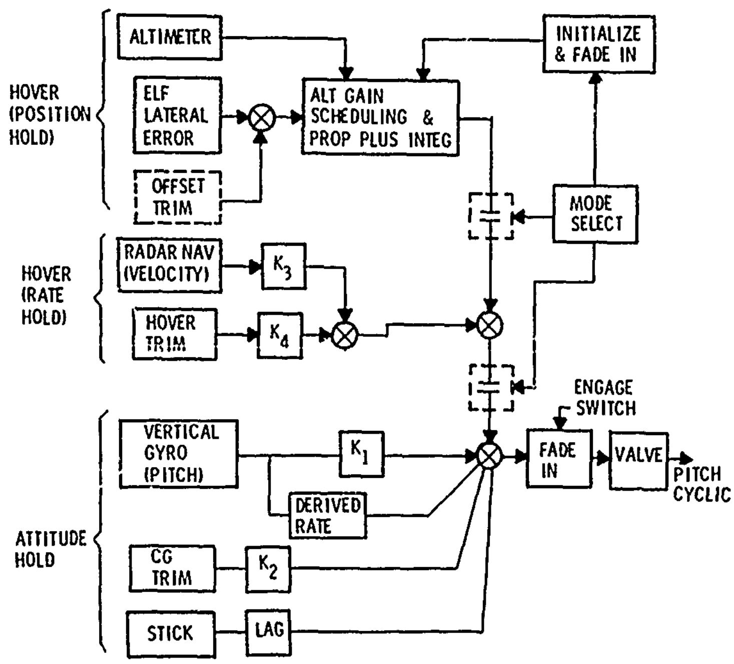


Figure 23. Pitch Channel Hover with ELF Tie-in

The choice of a homing track or path to be used must, in the operational situation, take many variables into consideration such as terrain, potential enemy interference and wind, as well as the nature and performance limits of the rescue equipment and aids.

However, in general there will be a wind condition with a crosstrack component, and an approach to hover into-the-wind is highly desirable.

It is to be observed that a flight path that is constrained by maintaining aircraft heading toward the rescuee will be a curved ground track of increasing curvature as the velocity and range decrease, ending up over the rescuee in an into-the-wind attitude (Figure 24). A straight-in, shortest-distance approach would require a crabwise approach ending up in a sideways movement over the rescuee, a maneuver that eliminates use of the LLLTV until the very last moments, since it is not trainable about the longitudinal axis of the aircraft.

The ELF lateral signal is a function of the angle between the longitudinal axis and the direction to the rescuee's transmitter. Thus, if the aircraft is held to a yaw attitude that keeps this signal zero, the into-the-wind curved track will result. This permits the simplest mechanization of a homing mode and is probably the optimum choice. A straight-in mechanization can be made but would be less straightforward. A yaw-axis steering is likely to be adequate in the homing phase where lower airspeeds are involved and bank-angle steering is not suitable.

The beam-convergence characteristic of the ELF signal may require a gain scheduling related to range to maintain performance as the signal gain increases. And, as in the hover mechanization, an integration will provide zero offset as the heading-change signal is generated.

For a block diagram description of the heading (yaw) axis mechanization and the auto homing elements, see Figure 21.

Reduction of pilot workload during the final approach to the rescue can be achieved by providing an AFCS-ELF lateral signal coupler to the heading axis for use during the approach coupler phase. The final performance capability of such a system will again be a function of the ELF signal characteristics and of the heading loop improvements previously discussed.

Automatic Navigation - Given a navigation avionics system that can provide a compass heading or error-type signal, the possibility of providing further pilot workload reduction by a coupling to the AFCS can be considered.

The complexity of an automatic tie-in coupler and its performance will depend upon the navigator signals and the AFCS attitude loop systems. However, the following considerations should be noted.

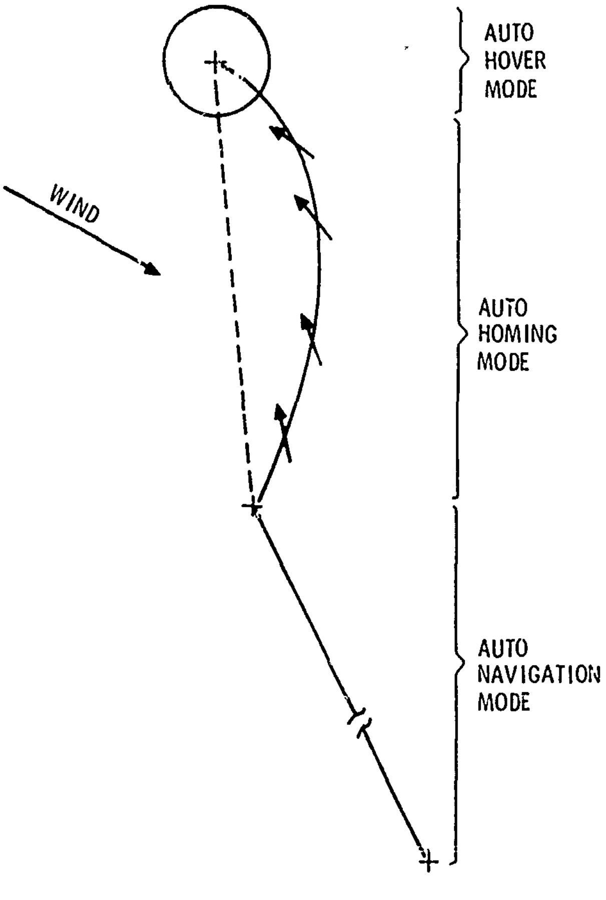


Figure 24. Automatic Modes for SAR Mission

Since navigation, unlike approach homing, will in general involve higher speeds, bank angle steering will be the normal mechanization. This will involve dealing with all three axes in the coupler mechanization. The need will, however, still exist to accommodate slow speeds where yaw-axis steering will be required. The transition between the two modes will require appropriate design treatment.

Conclusions

The AFCS improvements needed for the HH-53C SAR mission require both changes to increase performance of the present system elements and the provision for additional outer loop sensor signals.

A design definition and performance evaluation should be based upon an analysis using detailed aircraft - control system dynamic mathematical models. Only by this method can the present AFCS-caused limitations of the HH-53C in the SAR mission be removed.

SECTION V

RECOMMENDED SYSTEM

Costs and weights of the basic avionics, sensors and displays/controls to perform the USAF SAR mission are summarized in Table VI which is arranged to show a possible incremental installation of equipment in the order that improves the HH-53C SAR mission capability. It is recommended that the entire avionics complement be installed in a vehicle at one time rather than piece-meal installation over calendar time. The recommended avionics system is shown in Figure 25. This recommendation is based on the cost constraint of $500,000.

The preferred avionics system includes the flight director system, ELF, RHAW, projected map display, tape format engine performance displays, terrain following radar, raster CRT display, CRT symbol generator and LORAN C/D. However, this package exceeds the cost constraint of $500,000. Therefore, the CRT format symbol generator was removed, as a best compromise, to meet the cost constraint. Figure 26 shows the symbol display format of the AN/APQ-141 radar with the CRT symbol generator. When the symbol generator is removed from the avionics system, groundspeed, radar altitude, and camera-angle information will be removed from the display format. This means that the pilot's instrument-scan pattern must be increased on the approach to hover -- a delta increase in the pilot's workload during a critical mission phase.

FLIGHT DIRECTOR SYSTEM

The recommended flight director system is the three-cue system. It provides the greatest flexibility in selection of modes with minimum pilot workload. Additional navigation and tactical sensors can be integrated into the system. Although, the two-cue system does provide significant advantages in flying a helicopter IFR, the full potential of the helicopter under instrument flight conditions cannot be exploited until either the third cue or collective command is provided. In addition, the requirement for high-angle approaches to low minimums requires that automatic deceleration be provided during the approach to allow the helicopter to break out in a condition which allows easy transition to hover and landing.

The three-cue flight director system is being flight tested this spring at Fort Rucker, St. Louis (AVSCOM), and Edwards Air Force Base. The non-recurring costs will be ≈ $100,000. The delivery will start six months after receipt of the order. The three-cue flight director system includes ADI, HSI, computer, collective computer, control panel, and monitor display.

Table VI. Mission Capability Complement

Mission Capability/ Equipment Components	Component		Installed		Totals	
	Cost ($x 1000)	Weight (lbs)	Cost ($x 1000)	Weight (lbs)	Cost ($x 1000)	Weight (lbs)
Improved VFR Mission						
Flight director system	24	79	33.6	110		
ELF AN/ARD-21	GFE	60	GFE	84		
RHAW AN/APR-25/26	GFE	37.5	GFE	52		
					33.6	246
Improved Enroute Navigation at Low Altitude						
Projected map display AN/ASN-99	24.9	47.0	34.9	68		
Engine performance displays	15.0	16.0	21	23		
					89.5	337
IFR Terrain-Following Capability - Manual Nav. Update via Radar Fix.						
TF radar AN/APQ-141	200	132	280	185		
HSD PPI Type CRT	12.9	25	18	35		
TV raster display	GFE	25	GFE	35		
					387.5	592
Improved IFR TF Capability Auto Nav. Update - Reduced Nav. Workload						
LORAN C AN/APN-92	85	96	119	134		
CRT format symbol generator	40	11	56	16		
Remove HSD PPI	-12.9	-25	-18	-35		
					544.5	707
Recommended System-Delta Decrease in Flight Path Management Capability						
Remove CRT format symbol generator	-40	-11	-56	-16		
					488.5	691

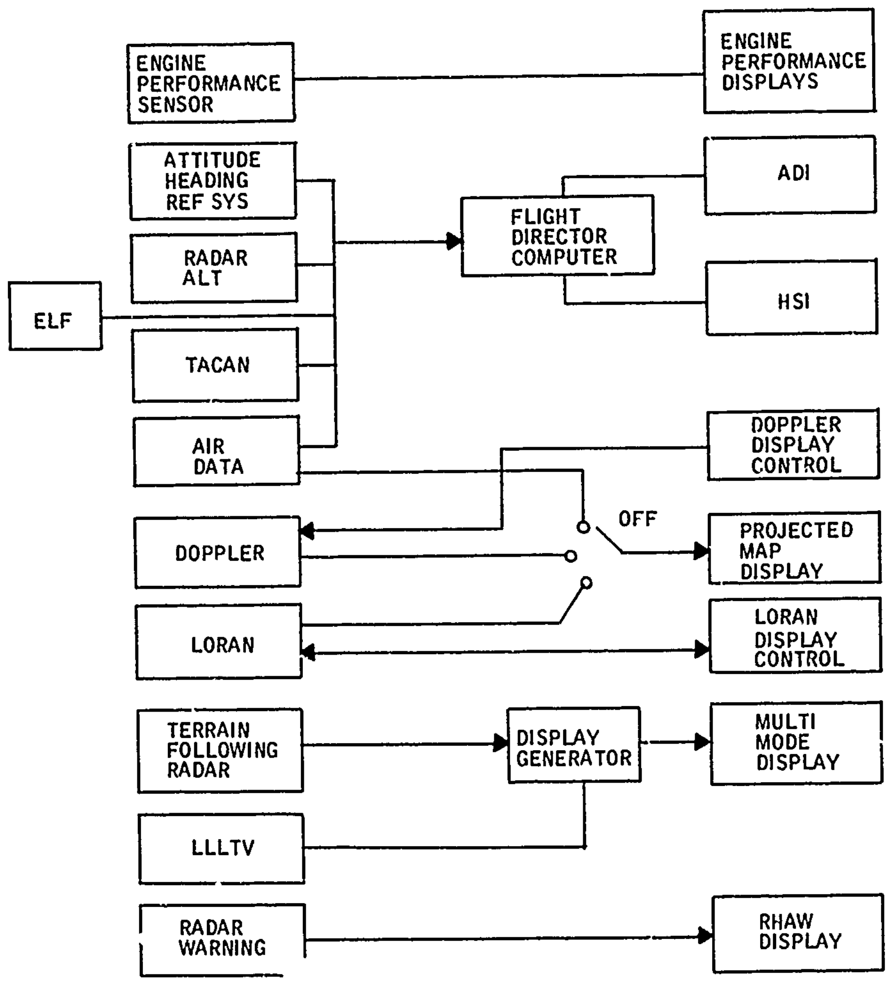


Figure 25. Recommended Avionics Configuration

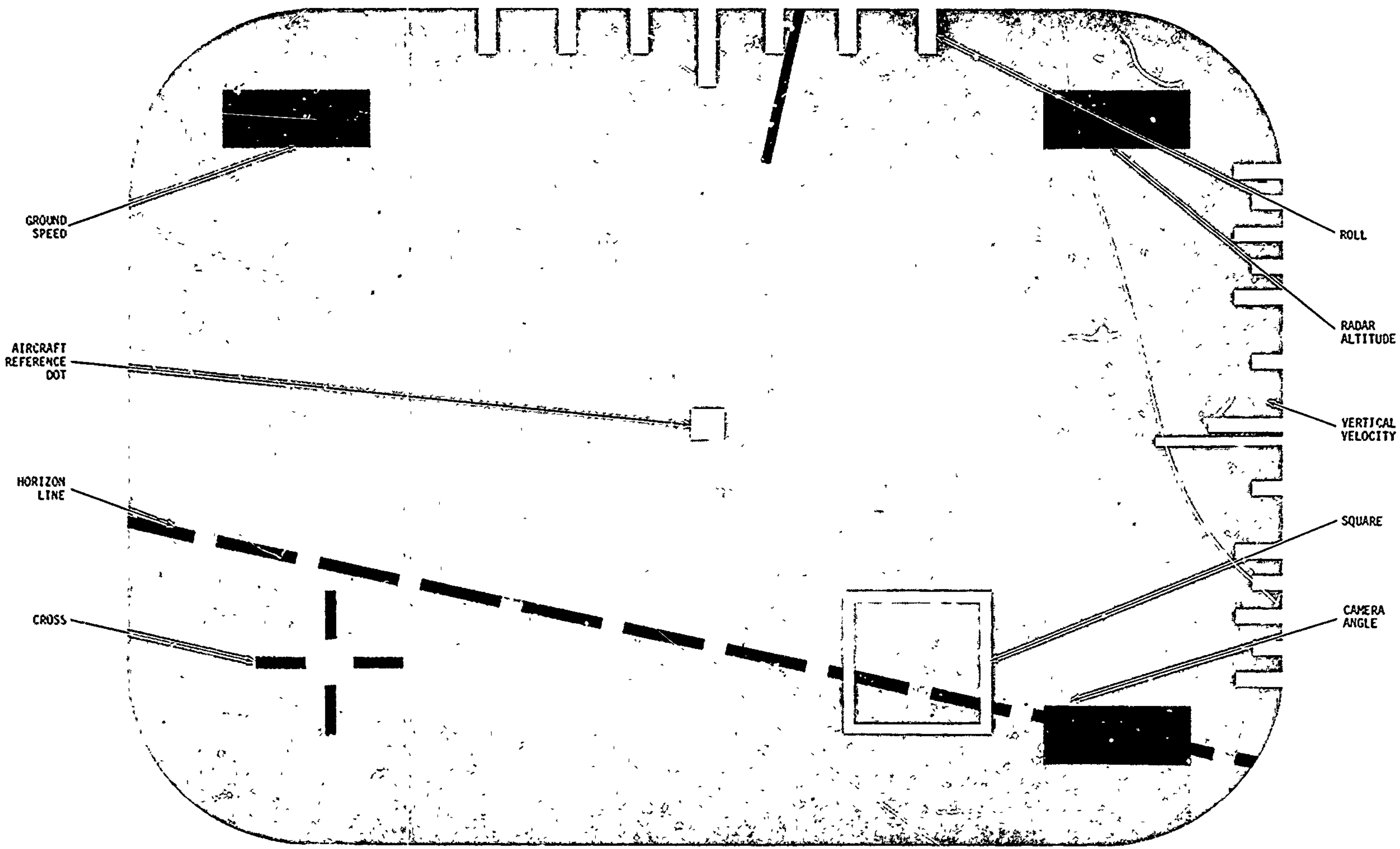


Figure 26. Symbol Format and Location

The additional features provided by the three-cue helicopter flight director system over those of the standard fixed-wing-version flight director are:

- Collective pitch command guidance for vertical path control
- ADF course select and flight director steering
- FM steering and station approach raw data integrated into the flight director display
- Attitude sphere pitch trim
- Airspeed mode on the flight director with automatic deceleration during approach for landing
- Flight director vertical speed mode for ascent and descent flight-path control, which provides vertical approach guidance in the absence of ground-based landing aids
- Takeoff/go-around flight director mode including attitude and airspeed control
- High-resolution radar altitude in the display, optimized for helicopter requirements range of 0 to 200 fect absolute altitude.

Mode Selection

The three-axis flight director is designed to give the pilot the greatest possible amount of flexibility in selection of modes while keeping the manual switching to a minimum. The pilot may select any lateral mode he desires; this will result in display of this command data on the vertical cross-pointer needle in the Attitude Director Indicator (ADI) as shown in Figure 27. Since the command data for each axis is presented on individual cues, those elements not required are biased from the pilot's view, thus reducing clutter in the display. Therefore, the pilot may choose the Heading Select mode, for example, and receive only bank command data. The same process follows for any longitudinal mode selected individually for display on the horizontal command bar.

Lateral Axis Modes -- Heading Select, VOR/LOC and Reverse Course are the major lateral command modes individually selectable. In each of these modes, a bank command is generated and displayed on the vertical command pointer in the ADI. Maintaining this vertical bar centered will cause the vehicle to turn to and hold a selected heading or to capture and track a desired radio navigation course.

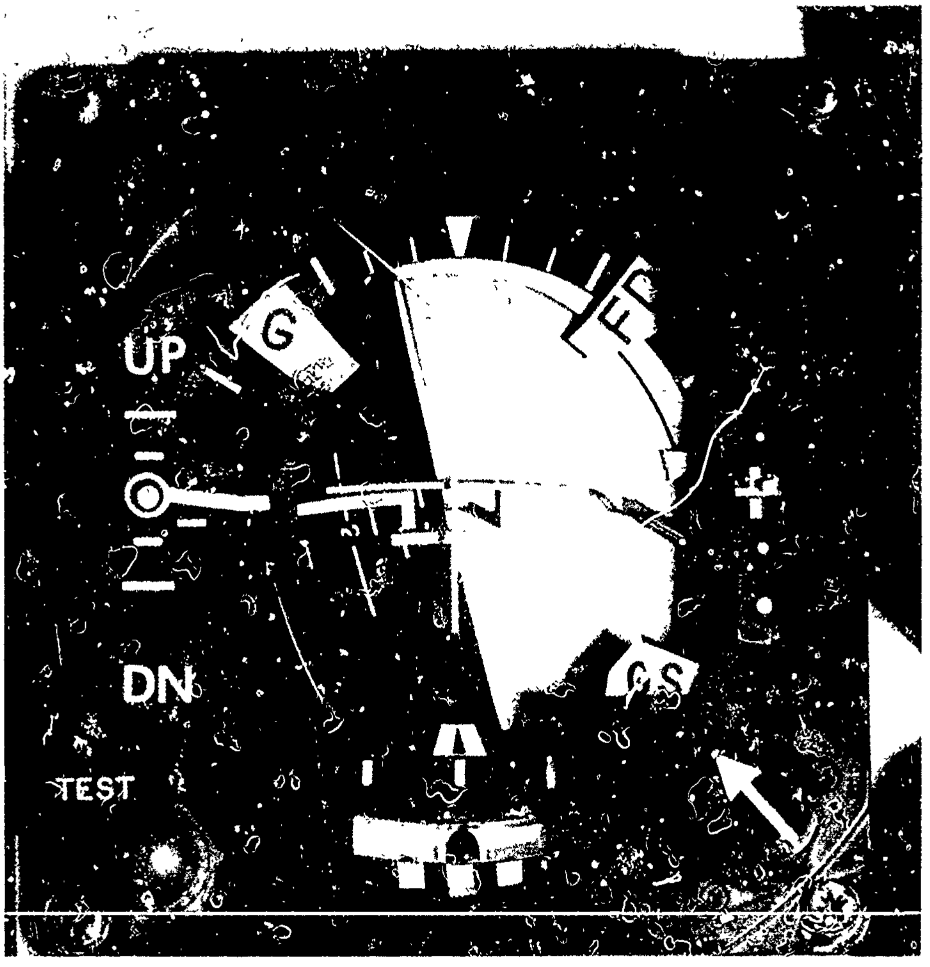


Figure 27. Attitude Director Indicator

Longitudinal Axis Modes -- Pitch Hold, Airspeed Hold, Altitude Hold and Glide Slope modes are available in the longitudinal axis.

In the Pitch Hold mode, a particular fuselage pitch attitude is selected and displayed on the horizontal command bar. This produces a greatly expanded pitch command for the pilot, which is easily reset to any convenient attitude.

Airspeed Hold may be selected to give the pilot a pitch command to attain and maintain a selected airspeed. This airspeed would be pilot selectable at any time before or during engagement in the manual airspeed mode.

Altitude Hold, when selected singularly or in conjunction with a lateral mode, will appear on the horizontal command bar. This mode is similar to the fixed-wing Altitude Hold mode in that the computer resolves engaged altitude error and pitch attitude to provide a pitch command.

Glide Slope modes are available on the horizontal command bar for a two-axis system subject to the same restrictions on mode logic as the altitude-hold mode discussed above. In this mode, vertical path control is accomplished by pitching the aircraft to cause it to track the glide-slope beam.

Collective or Power Axis Modes -- Presently, only two modes are included in the development effort. They are Altitude Hold and Glide Slope. Here the inputs to the computer are either altitude error or glide-slope beam error, as appropriate. These displacement signals are mixed along with their own derived rates to form collective commands.

HSI Flight Compass Indicator

The flight compass indicator (Figure 28) provides the pilot with a pictorial representation of his aircraft's position. The indicator combines ten radio navigation and compass displays into one compact area of the aircraft instrument panel. Each of the displays are distinctively shaped and have contrasting colors to facilitate their interpretation and assure their visibility. Appropriate warning flags and annunciators advise the pilot when invalid data is presented.

Heading information is displayed by the easy-to-read rotating heading card. The aircraft heading is read under the fixed index (lubber line) at the top of the instrument. A d-c torque motor is used to drive the heading card. This motor reduces the power consumption within the instrument and the consequent heat generation which always decreases instrument life. The high-torque d-c drive also eliminates the need for complex gear mechanisms.

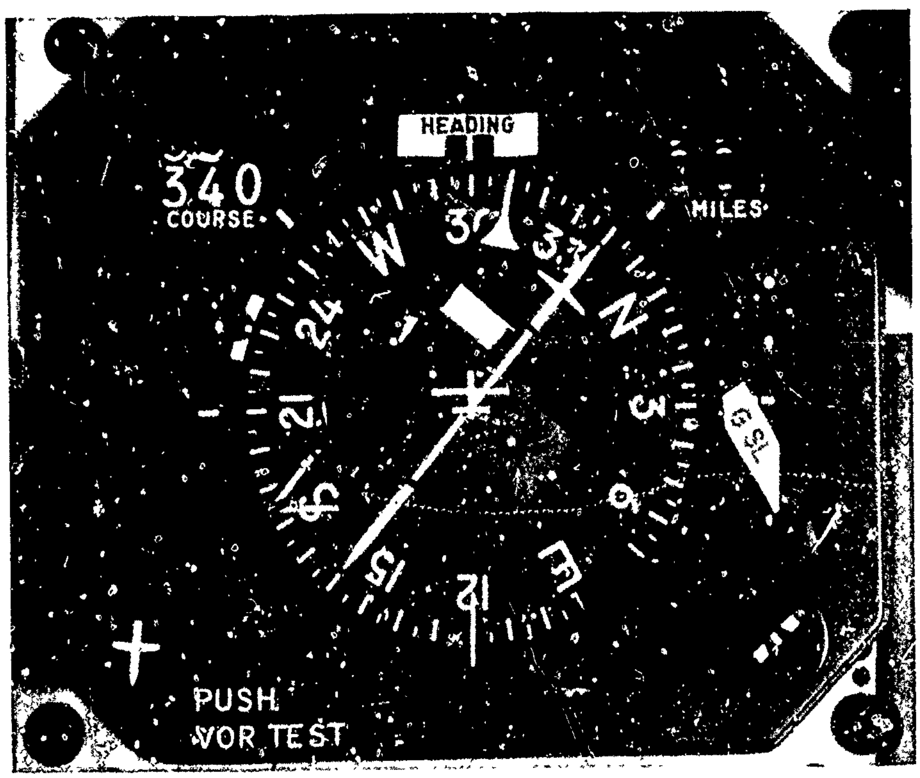


Figure 28. Flight Compass Indicator

Flight Director Computer

The flight director computer automatically compensates for crosswind effects during ILS approaches and VOR radial tracking while providing for smooth intercept of ILS localizer or VOR radial from any angle. Features include automatic beam-edge sensing, which reduces pilot workload and assures smoother flight transitions by automatically switching computer mode upon intercept of a selected radio beam. This feature allows the pilot to select VOR or localizer tracking on the mode selector while following a compass heading or to select glide slope while in attitude-hold mode. Upon approaching the selected radio beam, the computer automatically switches to the new mode.

Information furnished to the HZ-6F flight director is safeguarded by the system monitor (SMART). The monitor will detect system malfunctions and withdraw one or both flight director bars from view, thus preventing the use of incorrect information while leaving valid commands displayed by the remaining pointer.

RHAW EQUIPMENT

The mockups of the radar homing and warning (RHAW) azimuth and control indicators were fabricated from the outline dimension drawing supplied by Collins Radio Company. The system shown is AN/APR-25/26. It is located on the panel for primary viewing by the pilot. The feature and characteristics of the system are classified. It will be a GFE item for this installation.

The installation of the RHAW equipment should be installed at the first aircraft modification if more than a one-step modification program is followed. The RHAW installation improves the aircraft survival capability in a hostile environment. Its recommended location on the panel (Figure 29) does not interfere with the installation location of other display/control units on the panel.

ELECTRONIC LOCATION FINDER (ELF) SYSTEM

The ELF system provides the capability for the helicopter to:

- Hover precisely over a ground transmitter
- Follow steering information enabling the helicopter pilot to find the transmitter from long range

Locating the rescuee exactly from a position within the range of a location sensor such as ELF may be considered for a completely automatic control.

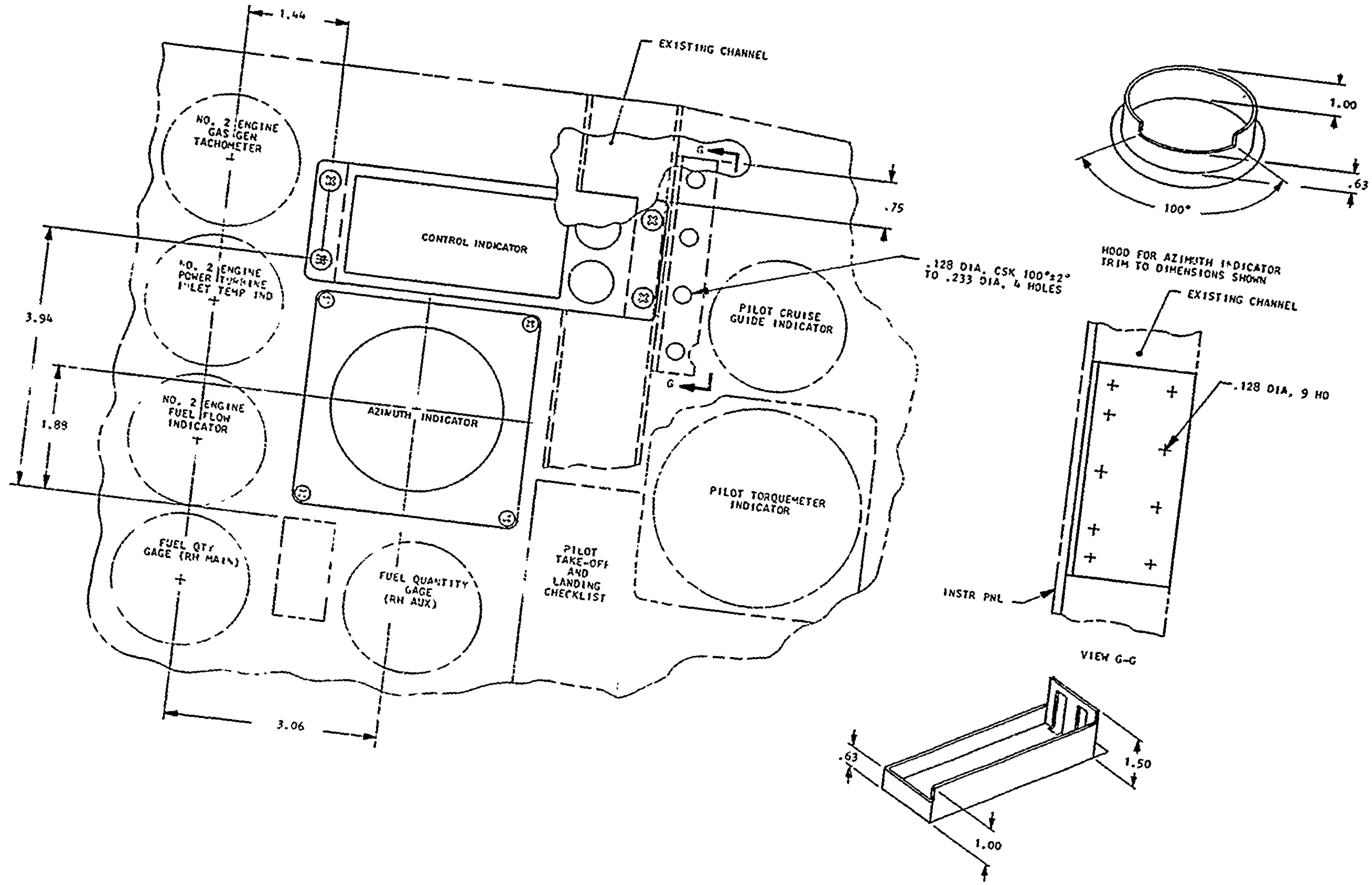


Figure 29. Control and Azimuth Installation

It is recognized that the altitude and velocity profile to be flown is critical to this portion of the mission. The report of flight test results produced by manual tracking of the needles was very satisfactory.

The ELF is proven, existing equipment, AN/ARD-21. The equipment is simple and consists of two receiver-processor units, which can be mounted at any convenient point in the helicopter, a control unit, and a four-antenna array. Antennas can be installed as an integral part of the helicopter or externally mounted to hardpoints.

The left-right and fore-aft steering information is displayed to the pilot on the ILS needles on the flight director. Therefore, the ELF system should be installed during the vehicle modification program in which the flight director system is installed.

ELF is designed to locate radio sources regardless of modulation content. Working on a total-energy-per-bandwidth concept makes this possible. Depending on the application, ELF may be configured to operate at any desired frequency if the wavelength is not so large as to make the antenna array size impractical. Using a CW source of 200 mw, the ELF will acquire out to 50 nm under line-of-sight conditions and provides an overall hover accuracy of better than 3 degrees. Using ELF as a terminal-area precision guidance system makes SAR rescue missions possible in all weather.

VERTICAL TAPE PROPULSION PERFORMANCE DISPLAYS

The installation of vertical tape display formats of engine performance data was required by the panel arrangement. The use of vertical tape displays make available considerable prime instrument panel area. The proposed arrangement of the engine performance parameters is shown in Figure 30. The parameters displayed are power turbine RPM, turbine interstage temperature, engine oil temperature, nose gear box oil temperature, main gear box oil temperature and pressure, hydraulic system pressure-main 1 and 2 and utility, fuel flow for each engine and total flow, and fuel quantity by main and auxiliary tanks with a digital readout of fuel remaining. The design is for a horizontal alignment of parameters for the normal cruise flight condition.

The history of vertical tapes, as reported by S. Moreland of USAAVSCOM, is that vertical tapes have higher development costs and lower initial reliability when compared to conventional round-dial instruments. However, the state of the art of vertical tapes has improved to where the replacement displays for the OV-1 aircraft are half the cost of the present installation. The Air Force should be able to benefit on a cost basis from the Army's vertical tape development program. By Moreland's report, the advantages of vertical tape over conventional round-dial engine instruments have been clearly

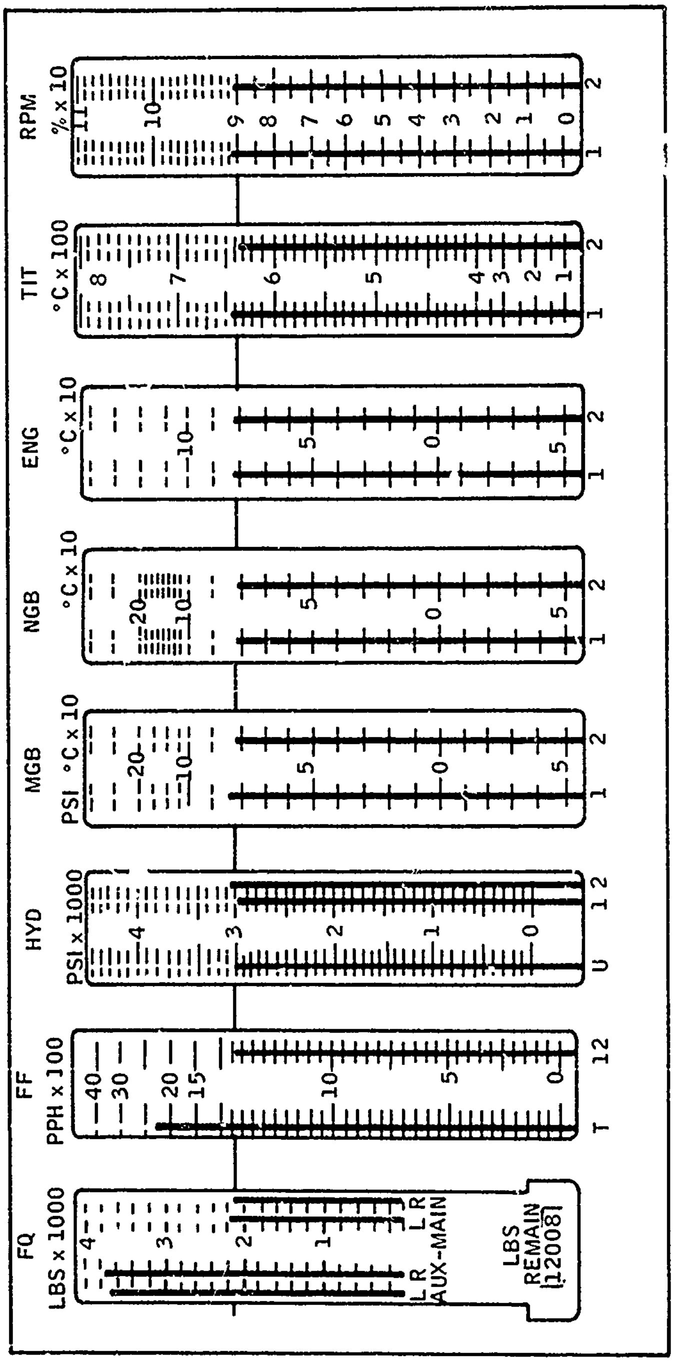


Figure 30. HH-53C Engine Performance Display

substantiated experimentally and operationally for aircraft use. Briefly summarized, the significant features and differences of the two types of displays are:

- Military and industrial studies have shown that the use of vertical tapes will save up to 50 percent of the space required by round-dial instruments. A study of the OV-1 indicates that the use of vertical tape instruments represented approximately a 38 percent saving of the instrument panel area currently used by conventional round-dial instruments.

- Pilot quick-scan monitoring ability, reading time and reading accuracy is significantly better usi~g vertical tape instruments.

- There was no significant parallax problems in reading vertical tape instruments, whereas serious reading errors will occur if viewing angles of round-dial instruments are increased over 40 degrees from normal.

- The illumination o:' vertical tape instruments is far superior to conventional round-dial instruments, due mostly to the inherent design of each type. The vertical tape displays also have clear color coding of the operating ranges of the display face under monochromatic (red) cockpit lighting. Only shades of gray can be seen of the color band of conventional dials under red illumination.

- The newer vertical tape instruments respond as fast and are as accurate as most round-dial type instruments and may also be operated accurat:ly under a wider range of input voltage fluctuation.

- Significant weight reductions can be experienced if state-of-the-art vertical tape instrum :nts are used in place of round dials.

- Projected costs per flight hour are less using the newer vertical tape instrument systems instead of the conventional dial instrument systems.

PROJECTED MAP DISPLAY

The projected map display, AN/ASN-99, was designed to provide the pilot with a simple, quick means of updating aircraft position in instrument as well as visual flying conditions by correlation with the mapping radar. The mapping radar mode is not recommended for the HH-53C installation. It is recommended to update the map display with LORAN C backed up by

doppler. The system does provide for maximum confidence in the aircraft's navigation system because it enables the pilot to relate his present position easily and accurately to a point on a map. In the past this has been done by translating the information from several displays to a hand-held map, an inefficient, time-consuming task.

The projected map display system is made up of:

- Projected Map Display (PMD 2-2) -- The display unit contains the 27-foot-long 35-mm film strip, film drives and feedback sensors, optical elements, map display screen, operating controls and peripheral display of: compass rose, miles-to-go and bearing to destination, ground track, and steering error. The display screen contains a graticule identical in form and scale to that on the aircraft radar display.

- Electronics Assembly Unit (EAU 1-2) -- The EAU contains the circuitry for receiving and processing the digital bit-serial, word-serial input commands from the navigation computer. The EAU provides closed-loop servo positioning signals to the PMD for each display parameter. The inputs are fully buffered for refreshing the servos at the required rates. Display control settings are indicated to the computer by discrete output lines.

The aircraft is usually represented by the circle engraved in the center of the 5-inch-diameter screen. At 1:500,000 scale the area visible on the screen is approximately 25 miles in diameter. To increase his ability to look ahead, the pilot may select the decenter mode; the aircraft is then positioned at the origin of the graticule near the bottom of the screen, thus providing the pilot with a forward viewing distance of approximately 22 miles. During normal mode, aircraft track is shown by the lubber line, which is read against the rotating compass rose. The display will be oriented track-upward or north-upward. In either mode, bearing is obtained by reading the bearing pointer against the compass rose.

When the "hold" button is pressed, movement of the map is under the direct control of the pilot who uses the joystick to "slew" the map to any position. This facility is used for updating and destination revisions and provides a closed loop to the computer for correcting the navigation system. Operation of the scale-selector switch automatically slews the film to the section which contains the appropriate area at the new scale.

Figure 31 shows the display format of the projected map display.

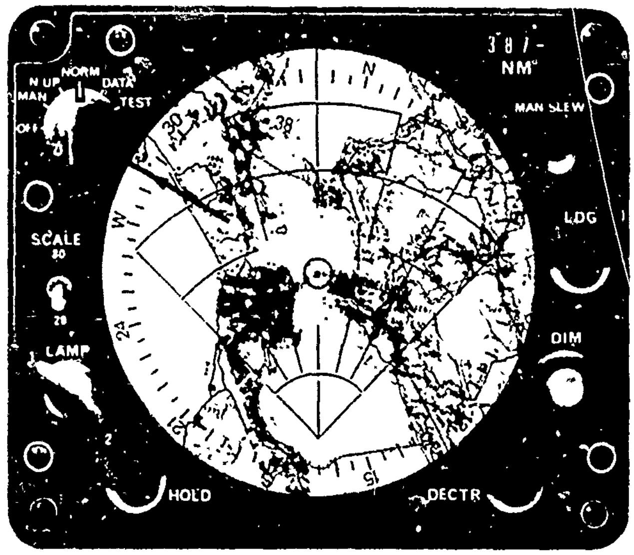


Figure 31. Projected Map Display Control Unit

Maps for the display are contained in cassettes, with each cassette containing about 27 feet of film. Cassettes can be changed readily and require no special tools or alignment procedures. Flight of the aircraft in an east-west direction is represented by motion of the film from one spool to the other, north-south flight is represented by motion of the carriage on which the cassette is mounted; and orientation is provided by rotating the cassetts through a complete 360 degrees. Both east-west and north-south movement of the film is automatic. When the film edge is neared the film is automatically slewed to the correct position on the next row. There is an overlap area between rows to avoid display gaps. The cassette completely encloses the film so that no surface of the film is directly exposed to the surrounding air. The film is accurately positioned and transported at high speed when required for frame advance.

The area that canbe covered on a single film cassette depends, of course, on the scales of the maps. Typical examples are:

Single scale	Area coverage (nm)
1:50,000	140 x 140
1:500,000	1400 x 1400
1:5,000,000	14,000 x 14,000
Two scales	
1:50,000 and 1:250,000	135 x 135
1:500,000 and 1:2,000,000	1250 x 1250

These area coverages are calculated assuming an over-magnification of the map image from the original paper map of 4:3 to permit easy reading at a 30-inch viewing distance from the screen. If the over-magnification is reduced, the area coverage is increased. For example, at 8:7 the coverage at two scales of 1:50,000 and 1:250,000 becomes 200 x 200 nautical miles.

The rationale for recommending the projected map display is that pilots tend to get lost when flying at low altitude.

Comprehensive trials in five separate tactical aircraft confirm that:

- The PMS increases the pilot's confidence in his navigation system.
- Position updating and destination revisions are simple, quick and accurate.
- There is a significant reduction in cockpit navigation workload.
- Operational mission effectiveness is dramatically increased.
- Using PMS, aircraft safety is vastly improved.

TERRAIN-FOLLOWING RADAR

The radar consists of the following line-replaceable units:

- Antenna
- Receiver
- Data processor unit
- Transmitter/modulator
- Control box

Each unit was designed using the latest solid-state and integrated circuit devices to achieve high reliability.

The radar provides the following modes of operation:

- Manual terrain avoidance (MTA)
- Automatic terrain following (ATF)
- Ground mapping (GM)

- Terrain clearance PPI (TCPPI)
- Airborne moving target indication (AMTI)

This mode information can be supplied simultaneously if displays are available. The terrain-following information will be supplied via a shades-of-gray processor and displayed on the LLLTV monitor in the cockpit.

The nonrecurring cost for this system will be approximately $2.5 million. The first unit can be delivered 14 months after receipt of order and one per month thereafter.

The use of the AN/APQ-141 (XN-1) all-weather terrain avoidance (TA) radar originally designed for the AH-56A Cheyenne compound aircraft permits safe, automatic, low-level flights with minimum exposure to the enemy. Simultaneously, with terrain avoidance, the radar provides ground map information for navigation purposes.

Manual terrain avoidance permits the pilot to safely guide his aircraft down the valleys giving him the advantage of minimal exposure to the enemy. In automatic terrain following, the aircraft is automatically guided in a straight path over the terrain, at a selected clearance altitude, relieving the pilot of the need to control the aircraft. This hands-off automatic flight considerably reduces pilot fatigue during extended terrain-following flights, leaving the pilot better prepared for arrival at the target or letdown area.

To provide manual terrain avoidance, a terrain-avoidance radar and display is all that is needed. Automatic terrain following (ATF) requires an ATF computer, radar altimeter, flight control system, and failsafe monitoring system in addition to the TA radar and display.

The compact, lightweight AN/APQ-141 (XN-1) TA radar provides this terrain-avoidance capability by accurately measuring terrain profiles over a wide sector ahead of the aircraft.

The Norden radar incorporates the phase interferometer technique, which inherently provides a rapid volumetric scan over wide azimuth and elevation angles. This technique determines the elevation angles electronically, eliminating mechanical scanning in the elevation plane. Coupling this rapid electronic elevation scan with a conventional azimuth scan gives the radar the wide field of view essential for good terrain avoidance. This wide field of view is scanned once each second, sufficient for subsonic aircraft.

The terrain elevation profiles determined by the radar are displayed on the Vertical Situation Display (VSD), also designed by Norden. The VSD provides a shades-of-gray terrain avoidance display. This display requires minimal interpretation, since it is quite similar to what the pilot would see out of the aircraft window under daylight conditions. Five range contours

are provided, highlighted by the different grey shades. These range contours provide accurate range information that can only be estimated by a pilot looking at the terrain. Aircraft altitude, velocity, roll angle, velocity vector, and flight command are displayed simultaneously with the range contours. This display, fed by the terrain-avoidance radar, provides all the information the pilot would need to safely guide his aircraft over the terrain. In manual terrain avoidance, the pilot controls his aircraft so that the velocity vector or impact point (+) stays within the optimum flight command (□) Figure 26. The pilot can make azimuth maneuvers where necessary in order to take advantage of the protection afforded by the mountains when flying down the valley. In automatic terrain following, the terrain-following computer automatically keeps the velocity vector within the flight command. During automatic flight, the pilot monitors his display to determine how well this is being done and whether the flight command is compatible with the terrain. The built-in test equipment automatically monitors the performance of the radar and provides a safe climb command in the event of a malfunction as well as a warning to the pilot.

In addition to terrain avoidance, the radar provides video for ground mapping or airborne moving target indication (AMTI). The AMTI capability becomes available when the necessary AMTI modules are plugged into the radar Data Processor Unit. Both these modes enhance the probability of mission success by providing additional useful information to the pilot. Ground mapping assists in navigation and target location. The AMTI provides detection of moving vehicles and personnel, particularly at night and in bad weather when the enemy is most active. These modes are displayed on a Horizontal Situation Display (HSD). The radar also provides terrain clearance plan position indicator (TCPPI) on the HSD by processing the normal ground map video to remove all returns from terrain below the aircraft's datum line. The display can then be used by the pilot to avoid all terrain that appears on the display. This type of presentation is useful to provide safe flights when it is not necessary to follow the actual contour of the terrain. The TCPPI display also permits terrain identification by comparing the terrain projection above the horizon with a topographic map.

HSD CRT MAP DISPLAY

The radar ground map display provides the crew with the capability to update the projected map display by radar position fixes. To exercise this capability requires almost continuous attention by the navigator. The disadvantages of this mode of operation are discussed in Section IV. It is not a recommended solution because of these disadvantages and the high workload it creates for the navigator.

LORAN C/D

The LORAN C/D is necessary to update the projected map display for the terrain-following mode. On the basis of the data by J. J. McGrath on low-altitude flight, pilots get lost a significant number of times in this type of flight:

> "In low-altitude flight the pilot is burdened with a large number of information and performance requirements. One of these requirements is that he maintain an awareness of his navigation position. This requirement has become known as 'geographic orientation.' (Geographic orientation should not be confused with the more familiar spatial orientation which generally refers to the pilot's awareness of the attitude of his aircraft.)"

Data gathered from 1000 Sandblower course flights indicate that:

> "Ten percent of the missions failed completely because the pilot became lost. In another 17 percent of the missions the pilot became lost but eventually reoriented himself and found the target area. In these cases the mission was compromised in many ways and under combat conditions might have failed. The remaining 73 percent were categorized as 'O.K.' Many of these missions failed too, but not because of geographic disorientation."

> "It is important to point out that the 'abort' and 'recover' percentages are minimum figures in that many cases of disorientation went unreported, and any case that was doubtful, or which had insufficient information, was thrown into the 'O.K.' category." (Figure 32 shows the frequency distribution of these disorientation incidents.)

> "The data can be interpreted more meaningfully in the form shown in Figure 33 which is a cumulative distribution of the data shown in Figure 32. The abscissa represents 'probability of disorientation' based on the percent of missions during which the pilot became lost. The ordinate represents the percentage of pilots who exceeded that probability. For example, by drawing a line horizontally from the 50-percent point on the ordinate to the cumulative distribution function, and thence vertically to the abscissa, it can be seen that half the pilots became geographically disoriented on at least 23 percent of their missions. As another example, by intersecting the function at another point, it can be seen that 15 percent of the pilots became disoriented on more than half of their missions."

The conclusions drawn from the McGrath study are:

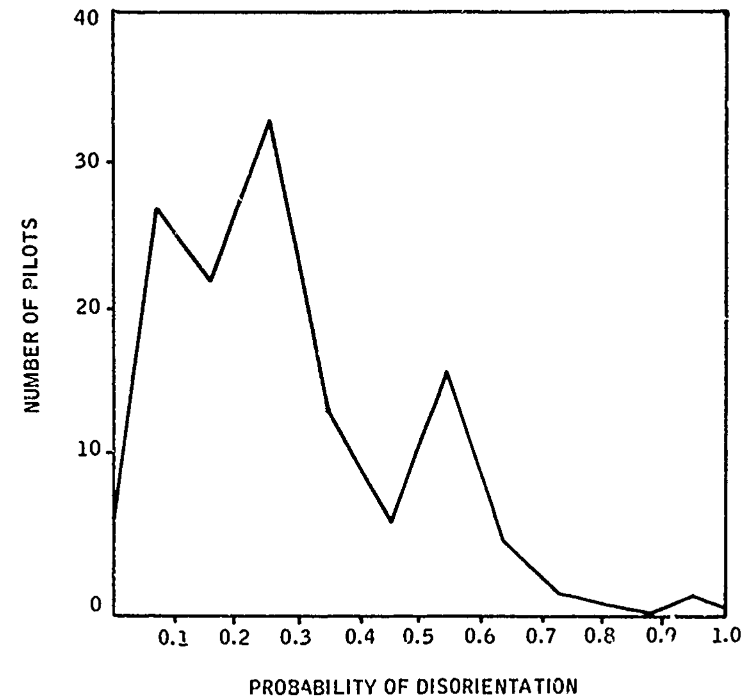


Figure 32. Frequency Distribution of Disorientation Incidents

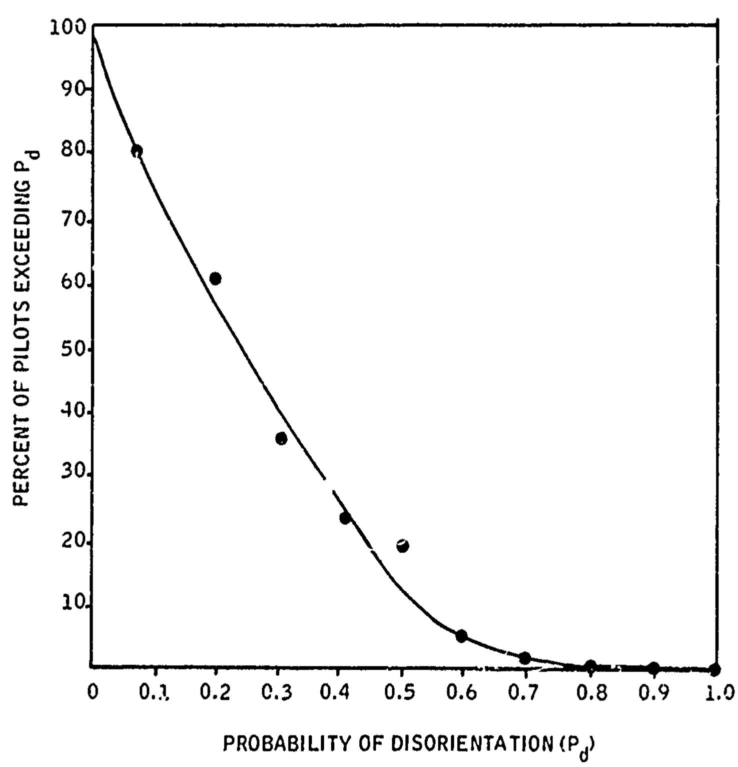


Figure 33. Probability of Geographic Disorientation

- A navigation update and efficient display system is required for low-altitude flight.
- Without proper navigation equipment, geographic disorientation will be frequent enough to significantly degrade HH-53C SAR mission success.
- Geographic disorientation takes a significant toll of aircraft and human life.
- Geographic disorientation is a general problem encountered by the majority of pilots.

The LORAN navigation system, designated AN/ARN-92, combines a LORAN receiver and a navigation computer that converts LORAN time-difference coordinates into desired navigation parameters for alphanumeric display on the control-indicator panel. The system is compatible with either permanent, long-range LORAN C stations or with the tactical mobile ground station, AN/TRN-21, LORAN D.

The system is designed for easy operation by the pilot of tactical aircraft. Two rows of gas tube displays show present position data for the navigation parameters, latitude, longitude, groundspeed, track, wind velocity, wind direction, time differences, true airspeed, magnetic heading, and UTM coordinates. The pilot/navigator also can elect to display navigation data relative to any one of four preprogrammed destinations in terms of:

- Latitude
- Longitude
- Range
- Bearing
- Cross-track error
- Along-track distance
- Estimated time enroute, provided course through destination is selected
- Course, with same provision
- LORAN time differences
- UTM coordinates

To provide these capabilities, the ARN-92 system is composed of three major units in addition to an antenna coupler unit which contains an activ low-noise amplifier and matching network.* These are the:

*Information from Aviation Week and Space Technology, April 1, 1968.

- C-7417 control indicator
- CP 898 navigation computer
- R1503 LORAN C/D receiver

Control Indicator

In addition to the gas tube display already described, the control indicator provides a keyboard for insertion of data or - in its display mode - for callup of desired data for display. It also contains controls for selection of LORAN stations and initiation of station search.

Navigation Computer

The navigation computer, made by Lear Siegler, utilizes that company's digital variable-increment computer (Divic) concept. The Divic computer is a general-purpose, serial machine with a special procedure for processing trigonometric problems. This computer, which operates on a binary system and has a 30-bit word length, provides a digital interface to the receiver and control indicator. It converts the receiver's time difference signals from binary-converted decimal to binary form and provides binary rate aid information to the receiver. It can convert the receiver time difference readings into latitude-longitude and UTM coordinates.

LORAN C/D Receiver

The LORAN C/D receiver, made by ITT Avionics, is composed largely of microcircuit elements, mostly Motorola flatpacks, mounted on plug-in microcomponent boards. Major improvements in the new receiver compared with earlier LORAN systems include the automatic acquisition feature and a several-fold increase in system accuracy, according to ITT. Automatic notch filters also contribute to reduced interference either from intentional jamming or from inadvertent sources.

The receiver is designed for a "one-man" operating environment characteristic of a fighter aircraft, rather than the flight deck of a large transport, and the number and complexity of operating controls for the receiver reflect this.

The automatic synchronization feature and automatic search result in an effective tenfold improvement in signal-to noise ratio, according to ITT. The new receiver automatically detects presence of sky wave, in addition, and instead of simply activating an alarm, as earlier receivers did, it continues to track but automatically favors ground wave when it becomes available.

The receiver's 3-db, RF bandwidth in track mode is 20 KHz and in search mode is 5 KHz at a 100-KHz carrier frequency. Instrumental accuracy of the receiver is 25 nanoseconds, and average accuracy of the entire system is ±120 feet.

ADDITION OF SYMBOL GENERATOR

Serious consideration should be given by the Air Force to adding the symbol generator to the avionics system for the HH-53C. The symbol generator provides a capability to redesign the display format in the future by adding or modifying a card. Thus, it is possible to develop a true optimized display format for the SAR mission and to design an optimum display format for each mission phase.

Such a display would provide the advantages of the "contact analog" type display and/or the instrument analog display and the skeletal displays. Because of the naturalness of the presentation, it reduces ambiguity and uncertainty about aircraft attitude and flight path. It will be relatively easy for the pilot to maintain his three-dimensional orientation in all mission phases with an optimized display format.

ALTERNATIVE AVIONICS COMPLEMENT

The alternative avionics configuration shown in Figure 34 contains an integrated navigation system. It is lighter and cheaper than the recommended system, and provides greater flexibility to change course enroute and to reduce geographic disorientation. It is a low-workload navigation system.

This avionics configuration is presented as an alternative to the recommended system because it would require a larger initial interface design study effort. The design approach is to replace the LORAN, doppler, and projected map display computers with two identical navigation computers. This arrangement would provide navigation computation redundancy, require only one computer in the inventory, and reduce the computer-operation workload of the navigator.

The design of the control unit should be based on a detailed analysis of the flight navigation tasks required for effective navigation in all phases of flight, including impromptu operations required by the hostile SAR environment. The primary requirement is for rapid error-proof entry and display of navigation data for flexible aircraft operation procedure.

Displays would be worked out for earth-oriented navigation compatible with the terrain-following flight path and the ELF terminal guidance system. This would be similar to the Canadian Marconi Company CMA-720 approach to RNAV. The CMA-720 has 64 standard ASC11 characters that can be

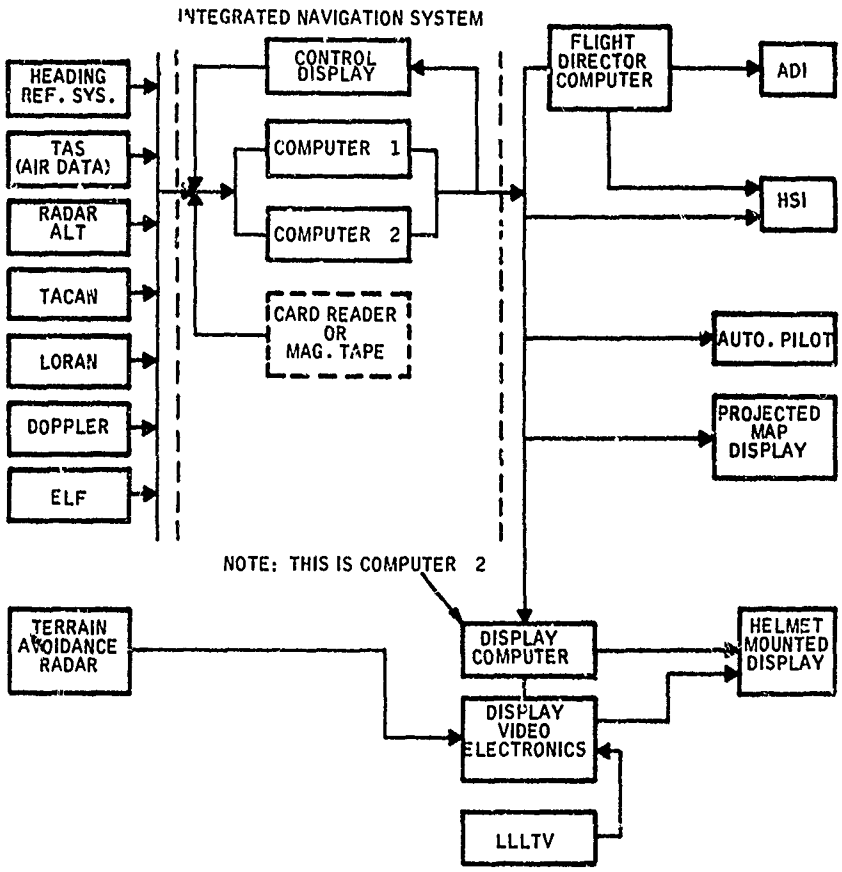


Figure 34. Alternative Avionics Complement

displayed in any position or sequence. The concept incorporates a form of time navigation. ETA is displayed for the current waypoint or for any waypoint when that particular data is called up.

DISPLAY PROBLEM

There is an apparent lack of confidence by helicopter pilots in the basic displays for use in instrument flight conditions. An example is airspeed at or below 40 KIAS. In the helicopter, this is a critical portion of the flight envelope. "If the pilot must look outside the cockpit for a measure of one flight parameter, he will generally tend to disregard other displays in the cockpit that give him good information." The deficiencies of some displays tend to affect the confidence that the pilot has in his whole system. The all-weather terrain-following SAR mission requires that the pilot have very high confidence in his whole display system. Both the pilot and the copilot must be heads-down in the terrain-following search, approach and hover mission phases. The general display problems exist in the areas of:

- Type of display
- Arrangement of displays
- Special display arrangement requirements versus mission phase

The specific HH-53C display problems are:

- Pilots' lack of confidence in displays for IFR
- The need for much higher-precision displays for SAR missions
- IFR hover versus initial position
- Vertical plane problems

The terrain-following flight-path management task presents special display requirements:

- The aircraft must hug the ground to get under enemy radar.
- The aircraft must hug the ground to get protection from small arms fire.
- The optimum terrain-clearance altitude must be determined.
- The aircraft path should match the terrain profile for best results; the problem includes:

(1) Aircraft response time lag after a control input

(2) Aircraft aerodynamic response

(3) g limit on aircraft maneuvers

- Aircraft must crest a peak in a level attitude.

- Pilots may be reluctant to pitch down upon command at small terrain-clearance altitudes.

There is the basic problem of a head-down display concept versus a head-up display concept. There are advantages to each concept:

- Head-down

  (1) All the information is inside the cockpit under IFR conditions.

  (2) No additional reference or other information can be gathered from looking outside.

  (3) Head-down eliminates the transition time from windscreen to instrument panel.

  (4) Head-down eliminates eye refocus time due to transfer of visual reference from outside to inside the cockpit.

- Head-up

  (1) The data shows that there is a powerful urge for pilots to want to look out during TF/TA flight, just to check.

  (2) For the case of LLLTV capability, the pilot can visually check external obstacles and check for alternate routes through the terrain.

  (3) Pilots have more confidence in the system due to the naturalness of the display.

Much work has been done on head-down and head-up (HUD) display development, but too little work has been done on evaluation of one versus the other. The helmet mounted sight display system (HMSDS) now offers increased performance and availability for an evaluation study versus the head-down concept that would be conducted within reasonable dollar and time constraints. Such a study would provide data for the develcoment of an optimum display concept.

DISPLAY ARRANGEMENT

Figure 35 shows the instrument panel mockup for the recommended avionics configuration. The instrument faces are designed to represent real display hardware. The instrument faces are mounted with magnets to permit easy changes of instrument positions. Figure 36 identifies each display. Figure 37 describes the communication panel arrangement.

There is a problem with clearance behind the panel. Data supplied by Sikorsky Aircraft Co. indicates the following clearances:

- At BL 24, 6 inches down from the panel top, there is 24 inches clearance; clearance goes to zero at the top of the panel.
- At BL 0, 7 inches down from the top of the panel, there is 22.5 inches of clearance.
- At BL 12-1/2, there is panel support structure with a 1-inch flange.

This constraint requires that the CRT displays must be located at the bottom of the panel, a nonoptimum location. The flight director system is a 9-inch-long box. This represents a potential clearance problem that must be checked out on an actual aircraft.

REPLACEMENT OF EXISTING VSI

The existing velocity steering indicator (VSI) has been replaced with a display that contains only groundspeed and drift-angle readout. The replaced indicator, installed with the AN/APN-175(V)-3 doppler radar, has the following capabilities:

- Displays information on only one display which is selectable by a switch.
- Displays selected destination relationship to present position.
- Displays north or south distance to destination by horizontal needle displacement.
- Displays east or west distance to destination by vertical needle displacement.
- Displays range by concentric range circles.
- Displays selected range of display face.

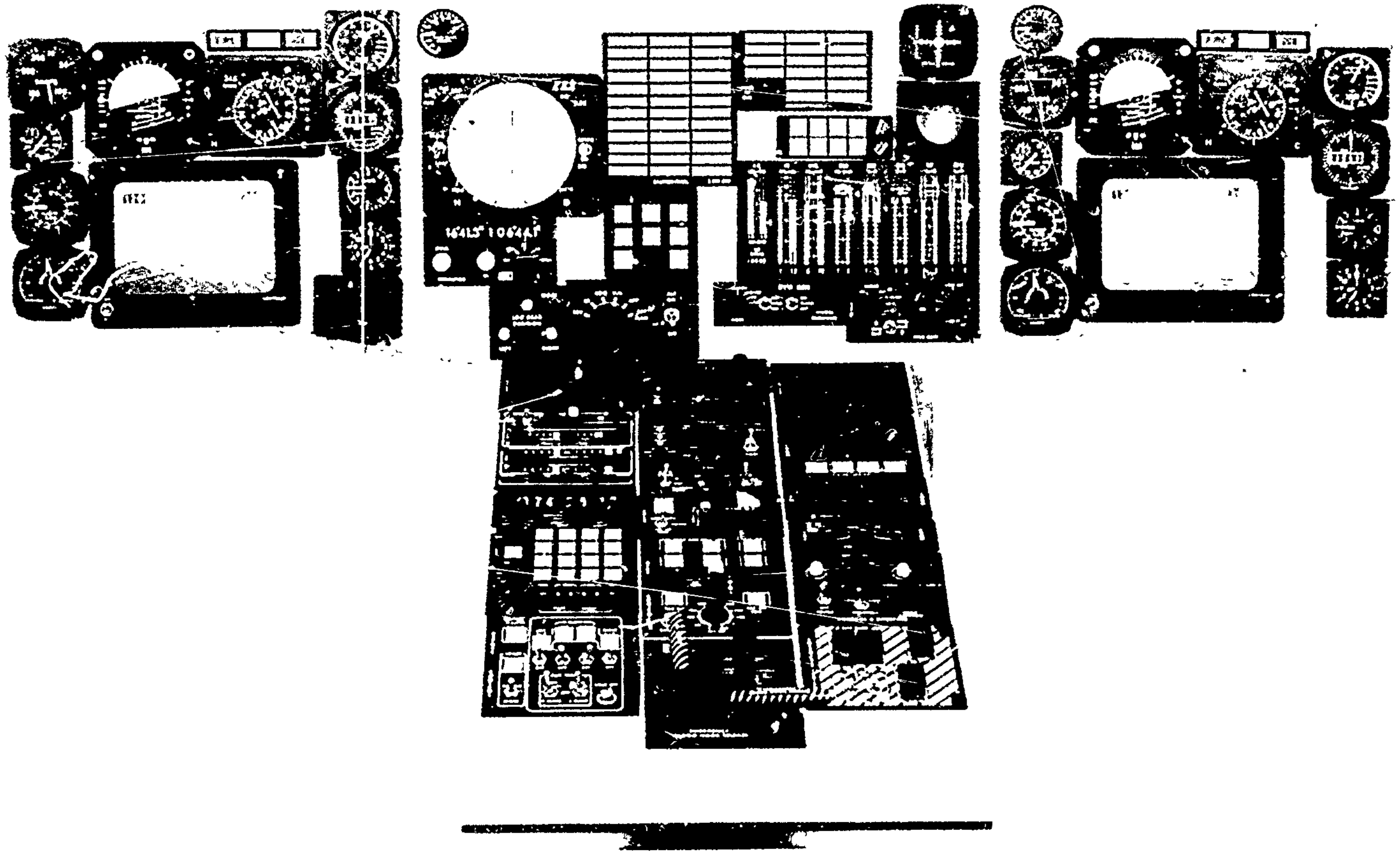


Figure 35. Instrument Panel Mockup - Recommended Avionics Configuration

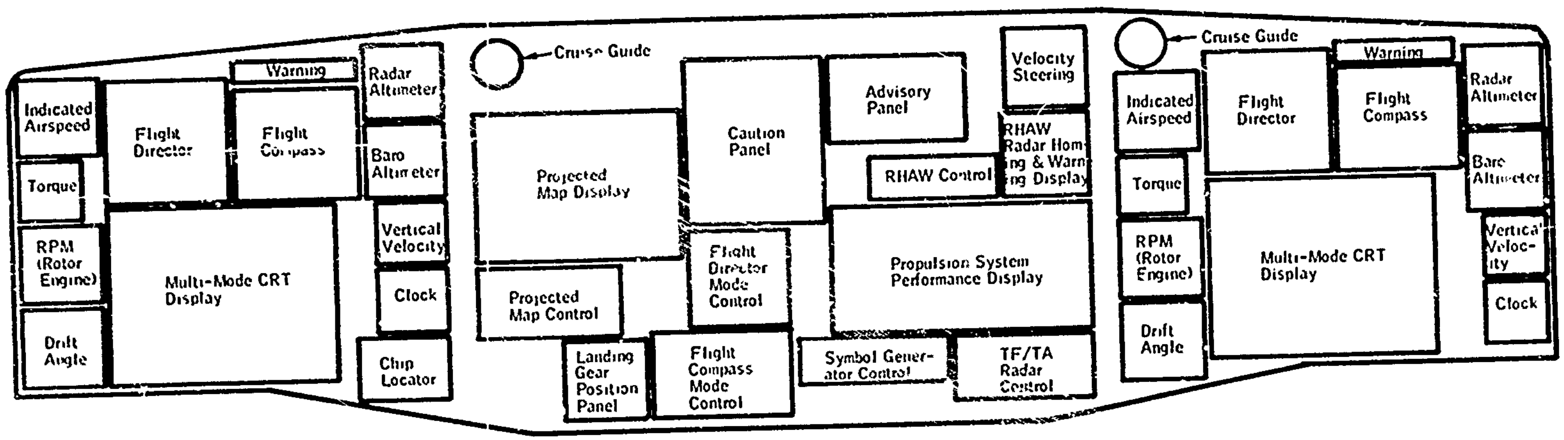


Figure 36. Instrument Panel Schematic

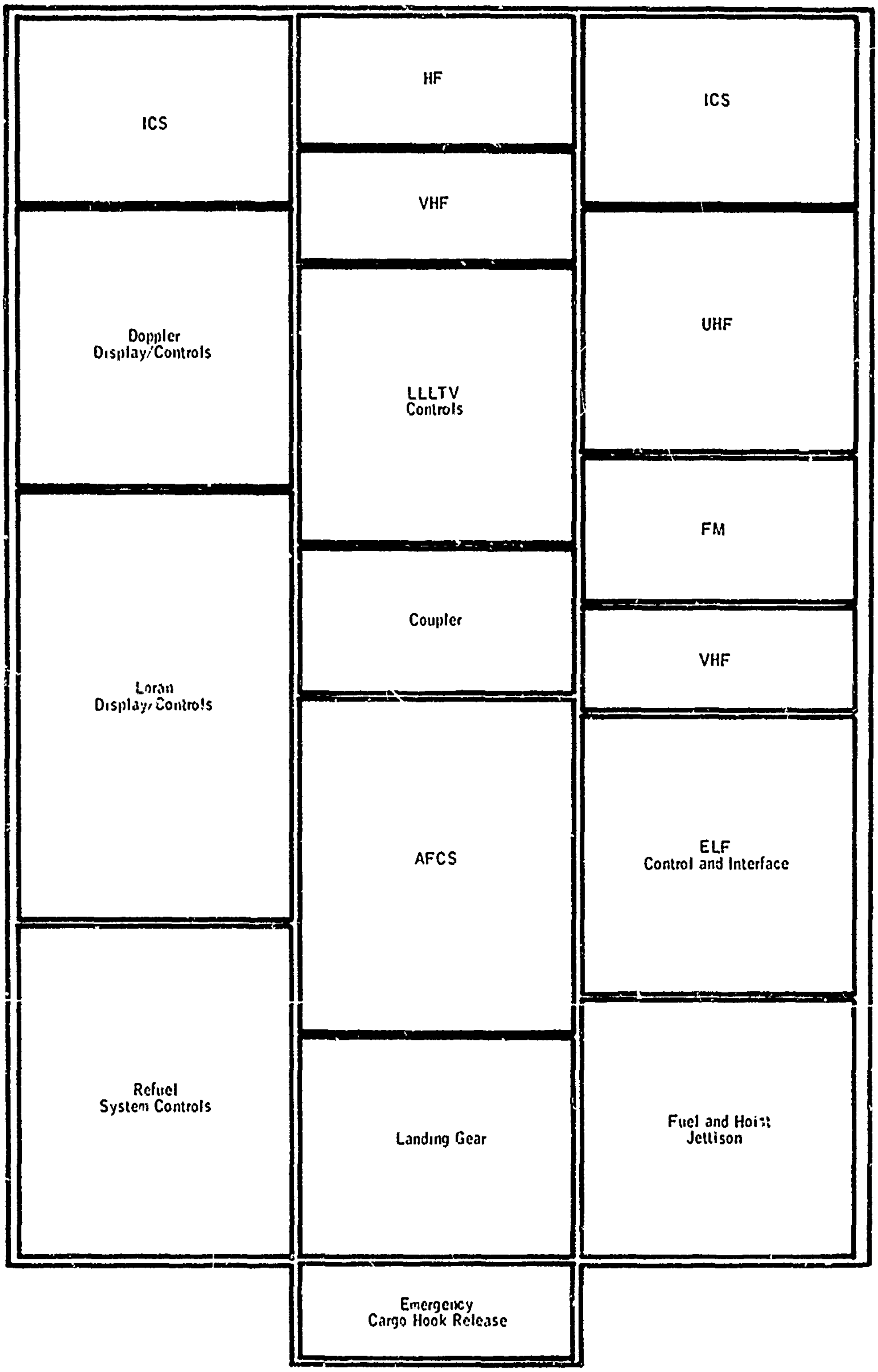


Figure 37. Communication Panel Schematic

- Displays true track.
- Displays stationary compass card.
- Displays wind velocity and direction.
- Displays ground speed in knots, 0-499 knot range.

The replaced display allowed the pilot to set in a wind manually. In addition, the desired track for the next leg could be entered into the display's memory. All of the above information is now contained in the LORAN C computer and can be called up as desired by the pilot.

The only information removed from the panel by replacing the VSI is the analog display of wind direction and velocity. Again, the wind information can be called up from the LORAN C computer as desired by the pilot. One VSI is retained at the pilot's station, located above the RHAW indicator, to facilitate checkout of the existing AFCS.